SAN FRANCISCO
WATER SUPPLY INVESTIGATIONS.

REPORTS ON

Conservation and use of the Waters of Tuolumne River.
Crystal Springs Reservoir; Water Unaccounted for.
Rainfall, Runoff and Water Utilization near San Francisco.
Pescadero Creek and Gregorio Creek as Sources of Water for San Francisco.
Runoff from Pilarcitos and San Andreas Watersheds.
Irrigation and Stream-flow in Sacramento Valley and in the Northern Portion of San Joaquin Valley.

By
C. E. GRUNSKY
Consulting Engineer.

January 4th, 1912

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San Francisco, January 4, 1912.

Mr. Percy V. Long,

City Attorney,

San Francisco, California.

Dear Sir:-

Herewith there are submitted for your information and use the results of my studies relating to a number of subjects connected with the sources of water which have been suggested as available for the supply of San Francisco.

By an unfortunate combination of circumstances the City met with unusual and unexpected difficulties in securing rights of way for reservoirs at Lake Eleanor, and on the Tuolumne River at Hetch Hetchy Valley, and is now by force of circumstances required to show to the Secretary of the Interior why the permit to use the Hetch Hetchy Valley should not be revoked.

In the first chapter of my report I have endeavored to make it plain that sooner or later the Hetch Hetchy Valley will be used as a storage reservoir. It is needed for the conservation of the water resources of the region tributary to the Tuolumne River. If these

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In the first chapter of my report I have endeavored to make it plain that sooner or later the Hetch Hetchy Valley will be used as a storage reservoir. It is needed for the conservation of the water resources of the region tributary to the Tuolumne River. If these

facts can be made apparent to the Department of the Interior it ought to settle the whole matter.

No one can claim a prior or a better right to the flood waters which can be stored in the Valley than San Francisco. This question is discussed at some length in the chapter on the Conservation and Use of the Waters of the Tuolumne River.

A second chapter is devoted to Crystal Springs reservoir, the large peninsula reservoir of the Spring Valley system. It appears from the records furnished by the Water Company that some of the water which flows into this reservoir remains unaccounted for. This fact was discovered when making comparisons between runoff and rainfall. It may have some bearing upon the future development of the system.

A third chapter is devoted to the watershed tributary to the South arm of San Francisco Bay. The rainfall and runoff in the various parts of this watershed are discussed as a basis for conclusions relating to the amount of water in this region that may be regarded as available for San Francisco.

In a fourth chapter consideration is given to the coast streams, particularly the Pescadero and San Gregorio Creeks, and their availability to supplement the production of the Spring Valley system.

The runoff from areas tributary to Pilarcitos and San Andres reservoirs of the Spring Valley system during three selected years is dealt with in a fifth chapter. The results of this study were used in estimating the water yield of coast streams.

The last chapter deals with the lower Sacramento and San Joaquin rivers as sources of supply. It is pointed out that there will ultimately be a demand by irrigators for more than the entire summer flow of these rivers; that the available portion of the natural summer flow of the rivers will be supplemented by water from storage; and that the amount of the return water reaching the streams after use for irrigation and domestic sppby will gradually increase, with a consequent deterioration of the quality of the water supplied by these rivers at their low stages. Such sources of water for the use of this city are not desirable so long as water from high mountain sources can be had at reasonable cost.

For dats furnished relating to the extent of irrigation in the San Joaquin and Sacramento Valleys I am under obligations to the Irrigation Investigations of the U.S. Department of Agricultural, and to the U. S. Geological Survey for records of stream flow.

Very truly yours,

(Signed) C.E.Grunsky,

Consulting Engineer.

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C. E. Grunsky, Consulting Engineer

December 26th, 1911.

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CHAPTER I.

CONSERVATION AND USE OF THE WATER OF TUOLUMNE RIVER.

CONSERVATION AND USE OF THE WATER OF TUOLUMNE RIVER.

by

G. E. Grunsky, Consulting Engineer.

1911

Tuolumne River is generally at a comparatively low stage from midsummer well on toward midwinter. The uninterrupted period of small discharge usually has a duration of six to nine months.

During the rest of the year 600,000 to over 3,000,000 acre feet of water run off from the watershed of the river.

The ultimate uses to which this water will be put will be irrigation, power development, mining, various other industries, domestic consumption, and, in some measure, navigation.

Tuolumne River is a tributary of the San Joaquin River, which is a navigable stream all the year in its lower reaches, and to points above the mouth of the Tuolumne River at high stages.

The requirement of water for irrigation in comparison with the requirement for all purposes other than navigation is large.

The water for irrigation is not wanted at a uniform rate throughout the year, there being a maximum demand for this purpose in the early summer months and a minimum during the cool winter months.

For power purposes there is no limit to the amount of water that can be put to beneficial use, but the use of water for the generation of power should be subordinated to higher requirements, such as the use of water for domestic purposes and for irrigation.

Notwithstanding this fact the importance of cheap power in the central interior section of the State which is sure to be densely populated in the course of time, makes it desirable that power development be not overlooked in a discussion of the water conservation on Tuolumne River.

If it were possible to entirely equalize the flow of such a river as the Tuolumne, so that the same quantity of water would be available every day this would be an ideal condition for power development. It would not be the ideal condition for irrigation nor even for the improvement of navigation in the San Joaquin River. Both irrigation and navigation interests would prefer to have the water liberated from the reservoirs at an uneven rate, but in the one case in amounts to meet the varying requirements of the crops, in the other to hold the main stream at a navigable stage as long as practicable.

In California there has, up to the present time, been no interference by Federal or State authorities with the taking of water from the tributaries of navigable streams,not themselves navigable, when the

appropriation was made for beneficial use as authorized by the State law. It is, therefore, to be assumed that navigation interests need not now be considered in a general discussion of the ultimate utilization of the waters of the Tuolumne River. These interests will benefit in some measure by any equalization of the flow for power and other purposes and will also reap the benefit of the return waters which are constantly increasing as the area of lands actually irrigated is extended.

In order that a proper basis may be had for a graphical study of the storage requirements on Tuolumne River, certain fundamental facts are to be considered.

The mean annual flow of Tuolumne River is about 2,000,000 acre feet. The water requirement by San Francisco and domestic use generally may for the purpose of this study be taken at a uniform rate per month throughout the year.

The requirement for irrigation is an uncertain amount, depending upon many factors not alone upon the area now under ditch, but also upon the ultimare success in preventing wasteful use of water and upon the additional area of foothill and mountain lands which will in the course of time be irrigated with water from this river. Whatever this aggregate use will ultimately be, there is one feature connected therewith concerning which there can be no doubt. The irrigation requirement is not uniform throughout the year. Taking one season with another and with due regard to the

diversity of crops and the small amount of rain in the winter months, the irrigation requirement of the year can be apportioned to the individual months about as follows:

January	1%	July	18%
February	3%	August	15%
March	4%	September	10%
April	8%	October	5%
May	15%	November	1%
June	30%	December	1%

This apportionment of the water to the several months is not suggested as the most desirable, from the standpoint of ultimate efficiency, because better results in the long run would be attained by a more copious use of the water in the spring and early summer with a corresponding reduction in the late summer and fall, but it is the requirement indicated by the actual use of water where the same can be had when the irrigator thinks he needs it.

On the basis of a total annual requirement of 3 acre feet of water per acre, the above percentage apportionment would be equivalent to 5.4 inches in May to 7.2 inches in June, to 6.5 inches in July and to 5.4 inches in August with correspondingly smaller amounts in the remaining months. These are average figures for large areas with diversified crops and there will of course be considerable departure therefrom for localities in which for any reason one character of crop, as for example alfalfa, is cultivated to the practical exclusion of all others. For a region all in alfalfa the summer requirement of water may be somewhat

greater and the winter requirement much less than indicated in the above percentage statement.

For the present ananytical purpose it may be assumed that the area sometime actually to be served with water from this river will exceed somewhat the area of the two irrigation districts now using water. Without endeavoring to set or assume a limit to the area that may thus be served, 300,000 acres are introduced into the calculation but merely as the basis for approximating the fluctuating water requirement.

The water required for this area during a large part of the irrigation season will exceed the ordinary flow of the river. If now there were no limit upon available properly located storage possibilities the utilization of the same would not only make the required irrigation water fully available when needed, but would also supply a large equalizing flow, during the months of low irrigation requirement, for the various other uses to which, so far as practicable, the water should be put.

There is no limit to be assumed for such other use except that imposed by the aggregate runoff from the watershed of the river as modified by the regulating effect of storage reservoirs and by the requirements of irrigation.

It is therefore proper to inquire what amount of storage throughout the river basin would

be requisite not only to adequately meet the irrigation requirement, but also to fully develop and conserve the flow of the river for all other possible uses.

Under such complete development every deficiency of natural flow during the irrigation season would be supplied out of storage and the surplus of the stored waters over and above the irrigation requirement would be used to equalize the stream flow in the remaining months of the year.

The discharge of Tuolumne River has been estimated for a period of six years,1878 to 1884 by the State Engineering Department of California and also for the years from 1895 to date by the United States Geological Survey. The results of these estimates are presented in the following tables,which as has already been stated, indicate a mean annual flow of the river of about 2,000,000 acre feet.

TABLE I

DISCHARGE OF TUOLUMNE RIVER AT MODESTO.

Estimate by the State Engineering Department.
(See Physical Data and Statistics of California 1886)

Acre Feet.

Month	1878-79	1879-80	1880-81	1881-82	1882-83	1883-84
October		1,844	3,443	7,993	43,678	16,110
November	3,868	6,010	2,082	11,484	33,917	19,457
December	3,996	55,523	67,328	38,122	20,106	20,106
January	29,391	25,148	177,330	38,122	40,211	25,210
February	104,187	35,950	375,153	31,823	27,213	28,185
March	171,980	51,157	177,022	133,059	80,548	402,129
April	265,150	424,918	372,459	210,823	194,578	437,950
May	312,726	637,687	447,261	458,759	502,968	452,548
June	420,158	837,521	310,909	478,770	389,157	486,743
July	121,560	468,412	122,729	168,783	100,532	402,129
August	11,253	75,814	84,041	35,294	30,129	100,532
September	2,321	7,973	7,437	13,388	19,457	19,457
Totals	1,446,589	2,627,957	2,087,230	1,626,420	1,482,494	2,410,556

TABLE II.

DISCHARGE OF YUOLUMNE RIVER AT LA GRANGE.

Estimates by the U. S. Geological Survey.

Acre feet

Month	1895-96	1896-97	1897-98	1898-99	1899-1900
October	10,380	9,330	14,650	4,680	32,960
November	7,780	69,440	46,700	3,750	145,970
December	18,760	68,560	68,880	17,220	188,830
January	144,120	76,690	29,400	31,420	148,070
February	68,850	288,240	51,410	42,530	58,820
March	169,540	248,920	76,740	224,320	150,710
April	311,470	461,260	240,280	310,930	148,950
May	274,330	734,120	285,550	279,980	427,530
June	459,600	338,600	135,140	363,030	320,460
July	186,640	135,100	18,510	64,260	50,890
August	31,790	15,570	6,710	13,910	6,880
September	27,640	6,120	2,620	4,430	2,910
Totals-	1,611,900	3,451,950	976,590	1,360,460	1,682,980

TABLE II. (Continued)

DISCHARGE OF TUOLUMNE RIVER AT LAGRANGE

Estimates by the U. S. Geological Survey.

Acre Feet

Month	1900-01	1901-02	1902-03	1903-04	1904-05
October	7,180:	12,970:	6,250:	4,430:	217,360
November	151,500:	34,160:	40,320:	61,760:	48,080
December	82,510:	83,330:	49,740:	26,560:	28,470
January	206,760:	21,640:	127,030:	26,690:	45,810
February	402,360:	80,140:	99,470:	237,390:	107,000
March	237,660:	140,810:	307,090:	383,790:	214,400
April	246,760:	297,700:	357,380:	381,180:	239,000
May	512,010:	409,260:	510,350:	718,210:	364,400
June	573,180:	412,070:	464,960:	569,810:	355,200
July	244,100:	86,270:	87,500:	182,620:	82,640
August	59,410:	23,240:	16,170:	47,280:	13,040
September	11,190:	5,420:	6,250:	38,800:	4,650
Totals-	2,803,620:	1,606,000:	1,973,110:	2,661,280:	1,720,050

TABLE II. (Continued)

DISCHARGE OF TUOLUMNE RIVER AT LAGRANGE

Estimates by the U. S. Geological Survey.

Acre Feet.

Months	1905-06	1906-07	1907-08	1908-09	1909-10
October	1,800	13,300	18,700	13,500	16,090
November	3,700	14,500	19,200	13,000	149,000
December	7,930	90,400	39,000	22,300	232,000
January	176,000	151,000	72,000	403,000	194,000
February	121,000	235,000	57,500	274,000	105,640
March	441,000	689,000	130,000	176,000	238,100
April	387,000	584,000	208,000	339,620	417,980
May	682,000	646,000	252,000	519,140	462,430
June	827,000	666,000	183,000	645,800	198,100
July	713,000	505,000	62,700	212,210	50,300
August	136,000	132,000	24,000	31,880	12,060
September	28,000	29,000	6,900	10,880	14,650
Totals	3,535,430	3,755,700	1,073,600	2,661,330	2,090,430

The value of a reservoir on a river such as the Tuolumne is dependent in no small measure upon its location. Waters for irrigation may be stored anywhere above the lands to be irrigated. If, however, the storage is high up on the stream the same water which the irrigator received may have already been used in the mining industry or for the generation of power. In so far as the regulation of the flow of the water to the irrigated field alone is considered, the reservoir location makes very little difference. For the full conservation of the water resources on the other hand, preference must be given to water stored high up in the mountains when conditions make such storage feasible. In other words, good reservoir sites high up in the mountains are of more importance in a scheme of water conservation than those in the lower portions of the drainage basin.

With reservoirs having an aggregate useful capacity of 2,500,000 acres feet, provided that these reservoirs are so located that water from all parts of the watershed can be intercepted thus preventing all waste, the ideal and extreme condition of water utilization on the Tuolumne River could be realized.

Unfortunately there is no probability that any system of storage reservoirs could be devised in the basin of the Tuolumne River that would fully meet this requirement. There will always be parts of the watershed

which at any time of heavy precipitation will be sending water to the streams in excess of storage facilities. This is particularly true of all that part of the watershed which lies below the drainage main storage sites as hereinafter enumerated.

It is, therefore, proper to inquire to what extent the flow of the Tuolumne needs regulation and whether the topographic features in the basin of the Tuolumne River are such that regulation of the stream flow for a fair utilization of its waters may ever be hoped for.

For the purpose of regulation, as will be shown, there should be a system of well distributed storage reservoirs constructed, of which the principal ones are so located that they will intercept,and will hold back until required, as much as practicable of the flood flow of the river, or rather of the water naturally flowing in the river in excess of the momentary requirement for all purposes.

The desirable,though probably not fully attainable,aggregate capacity of such a system of reservoirs, as will be shown, is about 1,160,000 acre feet. But even with such a reservoir capacity if the same does not afford an equal command of all parts of the watershed of the river the regulation may be imperfect.

Some of the reservoirs may be so located as to have low efficiency, as in the case of too small tributary area or by reason of requiring too long

and too expensive supply canals and in that case full utilization can not be attained.

In so far, therefore, as the storage which can be made available on Tuolumne River falls short of the above 1,160,000 acre feet, in so far will there be imperfect development of the water resources of this stream and consequently a reduction of the factor of utilization as applied to the entire stream flow.

The surveys which have been made in the past by the United States Geological Survey, indicate the feasibility of constructing the following reservoirs:

TABLE III.

Reservoir Sites reported by the U. S. Geological Survey

Tuolumne River Watershed.

Name	Stream	Height of Dam	Storage Acre Ft.
Bells Meadows	Big Canon Creek	60	6,300
Coffin's Hollow	Branch of Big Canon Creek	35	3,200
Hulls Meadows	Hulls Creek	50	3,160
Granite Lake		40	3,300
Cherry Valley	Cherry Creek	40	8,500
Lake Vernon		30	5,700
Big Meadows		30	11,000
Errarar's Meadows		30	1,070
Lake Eleanor	Eleanor Creek	65	45,770
Tuolumne Meadows	Tuolumne River	75	43,180
Hetch-Hetchy Valley	" "	150	107,400

These figures are based on definite assumptions by the United States Geological Survey in the matter of the height of the dams. The insignificance of

some of the storage basins examined may stand as an indication of the lack of good large sites in the high mountain regions, excepting only the Tuolumne meadows, Lake Eleanor and the Hetch Hetchy valley.

Some storage in the foothill region of the Sierra Nevada is to be added to these figures. The Modesto Irrigation District has constructed low earth dams impounding water in reservoirs known as the Dallas and Warner Lakes. It is reported that by flooding 3,000 acres about 30,000 acre feet of water can be stored and that it is feasible by raising the dams ten feet to store 60,000 acre feet.

Turlock Irrigation District has selected two storage sites, the one known as the Davis reservoir to store 48,000 acre feet of water on an area of 3,700 acres, and the Dickinson reservoir site to store 60,000 acre feet on an area of 4,100 acres.

Recent surveys by the City Engineer of San Francisco indicate that it will be quite feasible to construct higher dams at both Lake Eleanor and Hetch Hetchy than were contemplated by the engineers of the U. S. Geological Survey. In the case of Lake Eleanor it is possible to erect a dam, with an effective height, 150 feet which would impound about 212,000 acre feet, and at Hetch-Hetchy a

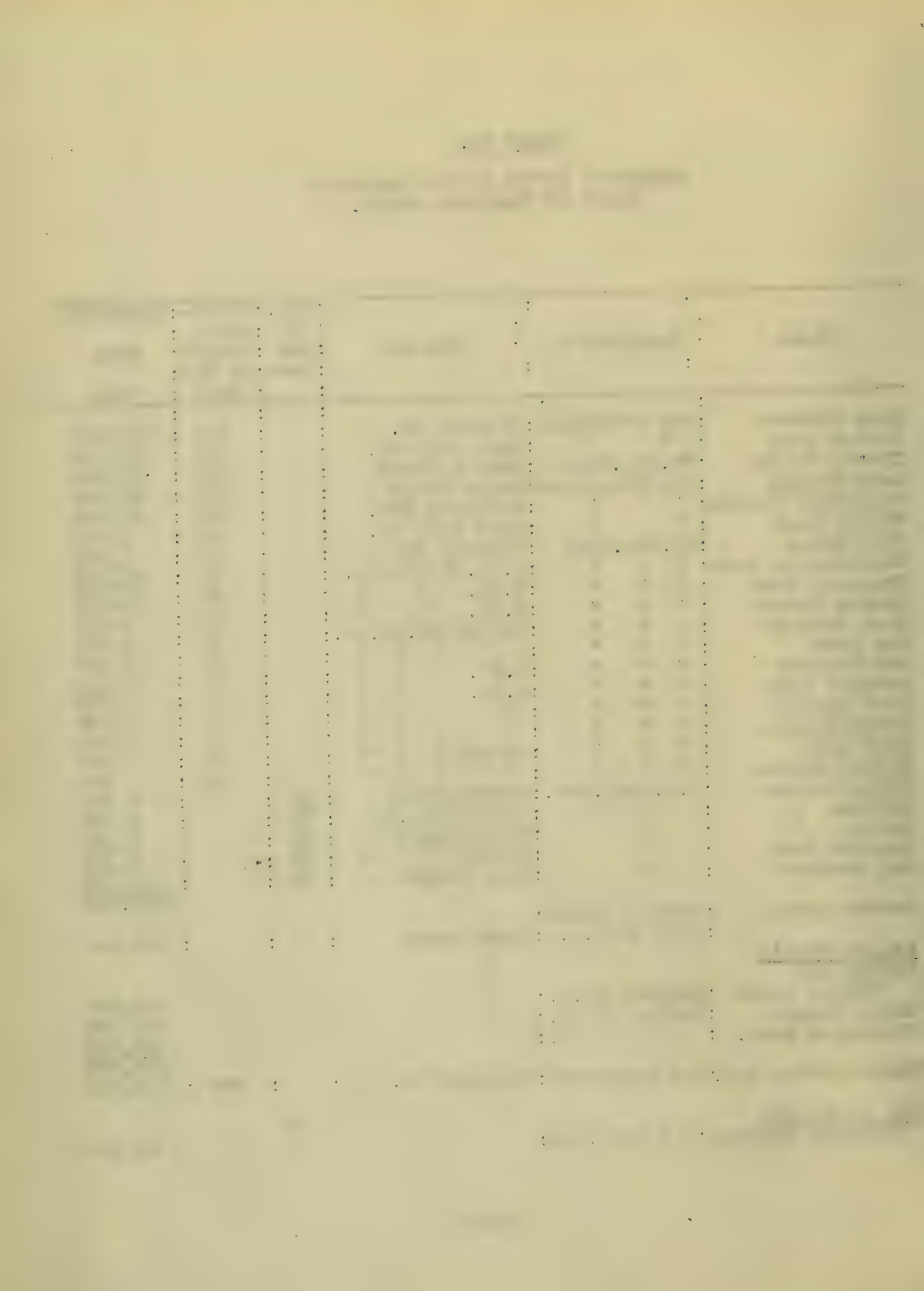
reservoir is under consideration which with a dam, having an effective height of 286 feet, would afford a useful storage space of about 435,000 acre feet.

San Francisco has also made surveys of some additional sites for water storage. Right of way permits have been granted to the City by the Department of the Interior for some of these. These sites are enumerated in the following table, together with the other known reservoir sites in the drainage basin of the Tuolumne River.

TABLE IV.

RESERVOIR SITES IN THE DRAINAGE
BASIN OF Tuolumne River.

Name	Surveyed by	Stream	Hgt. of Dam Feet	Effective Height of Dam Feet	Capacity Acre Feet
Lake Eleanor	San Francisco	Eleanor Cr.		150	312,000
Tilden Lake	" "	Jack Main Cr.		100	32,900
Cherry Valley	Wm.Ham.Hall	Cherry Creek		150	79,600
Lake Vernon	San Francisco	Falls Creek		100	50,900
Poopenaut Valley	" "	Tuolumne Riv.		150	27,900
Wilmer Lake	" "	Jack Main Cr.		100	8,800
Twin Lakes	Wm.Ham.Hall	Eleanor Crk.		30	4,579
Huckleberry Lake	" " "	E.Fk.Cherry Cr.		90	52,195
Emigrant Lake	" " "	N.Fk. " "		55	14,250
Louise Canyon	" " "	W.Br. " "		100	9,932
Buck Meadows	" " "	Relief Br.Ch.Cr.		30	3,058
Big Lake	" " "	" " " "		30	2,623
Cow Meadows	" " "	N.Fk. " "		45	4,710
Maxwell Lake	" " "	E.Fk. " "		30	2,779
Lord Meadow	" " "	" " "			1,459
Horse Meadow	" " "	" " "		30	1,023
Deer Lake	" " "	Relief " " "		20	862
Spring Meadow	" " "	" " " "		30	800
Bells Meadow	U.S.Geol.Sur.	Clavey River	60		6,300
Coffins "	"	Coffin Hol.Cr.	35		2,200
Hulls "	"	Hulls Creek	50		2,160
Granite Lake	"	Kibbie "	40		3,300
Big Meadows	"	Deep Canyon	30		11,000
					535,330
Benson Lake	Turlock &Modesto Irri.D.	Piute Creek			60,000
Fed by Canals					
Dallas and Warner Lakes	Modesto Ir.D.				60,000
Davis Reserv.	Turlock " D.				48,000
Dickenson Resv.	" " D.				60,000
					168,000
Hetch-Hetchy Val.	San Francisco	Tuolumne Rv.		286	425,000
Not Available					
Tuolumne Meadows	U.S.Geol.Sur.				43,180



Based on these larger projects the aggregate storage known to be available in the mountainous portion of the basin of the Tuolumne when topographic conconsideration alone are taken into account not including Tuolumne Meadows, would be about 960,000 acre feet.

Tuolumne Meadows is not likely to be ever used as a reservoir, because it is the most available central point from which a large part of the high Sierras can be made accessible to mountain tourists, and because in comparison with storage in the more available Hetch-Hetchy, whose watershed includes the area tributary to Tuolumne Meadows, its utilization is not of prime importance.

As shows in Table IV. there should be added something to the 960,000 acre feet for storage in the foothill reservoirs whose construction is contemplated by the Turlock and Modesto Irrigation Districts when estimating the total available storage capacity of all reservoirs.

The foregoing table represents the judgment of the United States Geological Survey in the matter of available reservoir sites some years ago, supplemented, as stated by recent surveys made by the City Engineer and by Mr. Ham Hall, whose interests on Cherry Creek and at Lake Eleanor are being acquired by San Francisco, and by information furnished by the Irrigation Districts.

If every reservoir site enumerated in the foregoing table, except Tuolumne Meadows, could be

utilized and made effective to the full extent of the capacity there noted, it would be possible to bring the utilization of the rivers flow up to about 75 per cent of its normal flow for which an effective storage of about 1,160,000 acre feet would be required.

But some of the reservoirs are on small streams with small watersheds, some must rely in whole or in part upon a water supply through canals,as in the case of Lake Eleanor and the foothill reservoirs of the irrigation districts. They may not be effective to their rated capacities.

Under these circumstances it will be difficult to show that the maintenance of Hetch-Hetchy as a meadow--even though some value, aside from its scenic features be granted to the meadow--will outweigh its beneficial effect upon the water conservation and water utilization on the Tuolumne River system if converted into a reservoir. The withdrawal of this site for all time from use for impounding water would decrease the known available aggregate storage capacity by 435,000 acre feet. The really effective remaining storage capacity would be less than required to properly conserve the water of Tuolumne River.

If Hetch Hetchy be not used as a reservoir there is not way of effecting the additional water utilization which, when converted into a reservoir, makes it possible. The value to the people of a body of pure mountain wat- whose regulating effect upon

The flow of Tuolumne river is probably equivalent to an addition of somewhat more per annum than its storage capacity or upwards of 425,000 acre feet, at an altitude of 3,700 feet, available not only for domestic use, the highest use to which water may be put, but available in addition thereto for the generation of an amount of power equivalent to about 50,000 horse power delivered continuously throughout the year, would be lost.

The rational development of the water resources on the Tuolumne River will include the conversion of Hetch-Hetchy Valley into a storage reservoir and it follows as a matter of course that San Francisco should have been granted her request for a reservoir right-of-way as soon as it was made clear that the City was acting in good faith and within her rights in filing upon the water of the stream.

The amount of water from the Tuolumne River that might possibly be applied to beneficial use if there were storage in adequate amount obtainable, may, for the purpose of showing the need of reservoir capacity for a reasonably full development, be taken at about 1,500,000 acre feet. This amount is obtained by deducting about 25% from the mean annual discharge, for necessary losses such as evaporation and waste owing to the manifest impracticability of so arranging all reservoirs that they will be capable of impounding all the runoff, come as it may. Some such waste

is to be expected in ordinary years and greater waste in the occasional year of excessive runoff, as for example in 1879-80, 1883-84, 1896-97, 1900-01 and 1903-04.

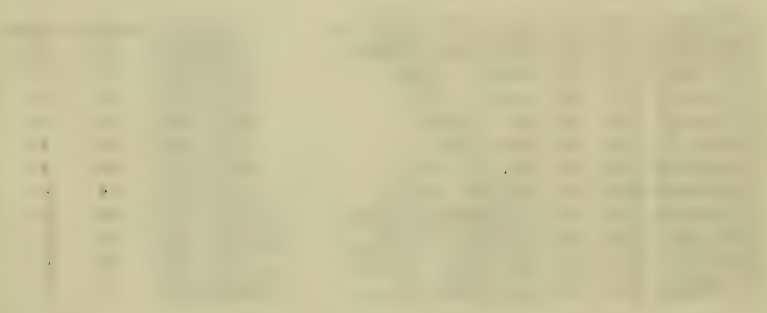
With due regard to the irrigation requirement of about 30,000 acres, this area, as stated, being introduced merely for the establishment of a basis for the monthly fluctuation in water consumption, and with due regard to the fact that the requirement of water by San Francisco, and for all other purposes will be practically uniform throughout the year, the 1,500,000 acre feet may now be distributed to the several months of the year about as follows:

January to March, per month	99,000	acre feet
April	107,000	" "
May	155,000	" "
June	200,000	" "
July	182,000	" "
August	155,000	" "
September	110,000	" "
October to December, per month	99,000	" "

The total consumption for useful purposes would be:

January 1st to January 31st,	99,000	acre feet
January 1st to February 28th,	198,000	" "
January 1st to March 31st,	297,000	" "
January 1st to April 30th,	404,000	" "
January 1st to May 31st,	559,000	" "
January 1st to June 30th,	759,000	" "
January 1st to July 31st,	941,000	" "
January 1st to August 31st,	1,896,000	" "
January 1st to September 30th,	1,206,000	" "
January 1st to October 31st,	1,305,000	" "
January 1st to November 30th,	1,404,000	" "
January 1st to December 31st,	1,500,000	" "

By constructing a curve with these figures and comparing the same with the mass curve of the



river's flow of past years so far as the records permit, the deficiency of the natural flow as compared with the possible utilization under adequate regulation at once becomes apparent.

From diagrams showing the mass curve of runoff from the watershed of Tuolumne River, such as shown on a reduced scale in Figs. 1 to 4, with the aid of the consumption curve as it would be under the indicated maximum utilization of water from the river averaging 1,500,000 acre feet per year, it is found that in the past there would have been a draft upon storage and a periodical surplus or deficiency of supply as indicated in the following table:

TUOLUMNE RIVER

Mass Curve of Discharge
and
Annual Mass Curve of Evaporation

for the municipal water system
of Tuolumne River for San Francisco

Scale - Million Gallons

TUOLUMNE RIVER

Mass Curve of Discharge
and
Double Mass Curve of Precipitation

for the watershed above
Hetch Hetchy Reservoir site

Scale: Million Gallons

Discharge in second feet ——
Run off in inches per month on watershed ——

Prepared for the
City and County of San Francisco
by
C. E. GRUNSKY
Consulting Engineer
1914

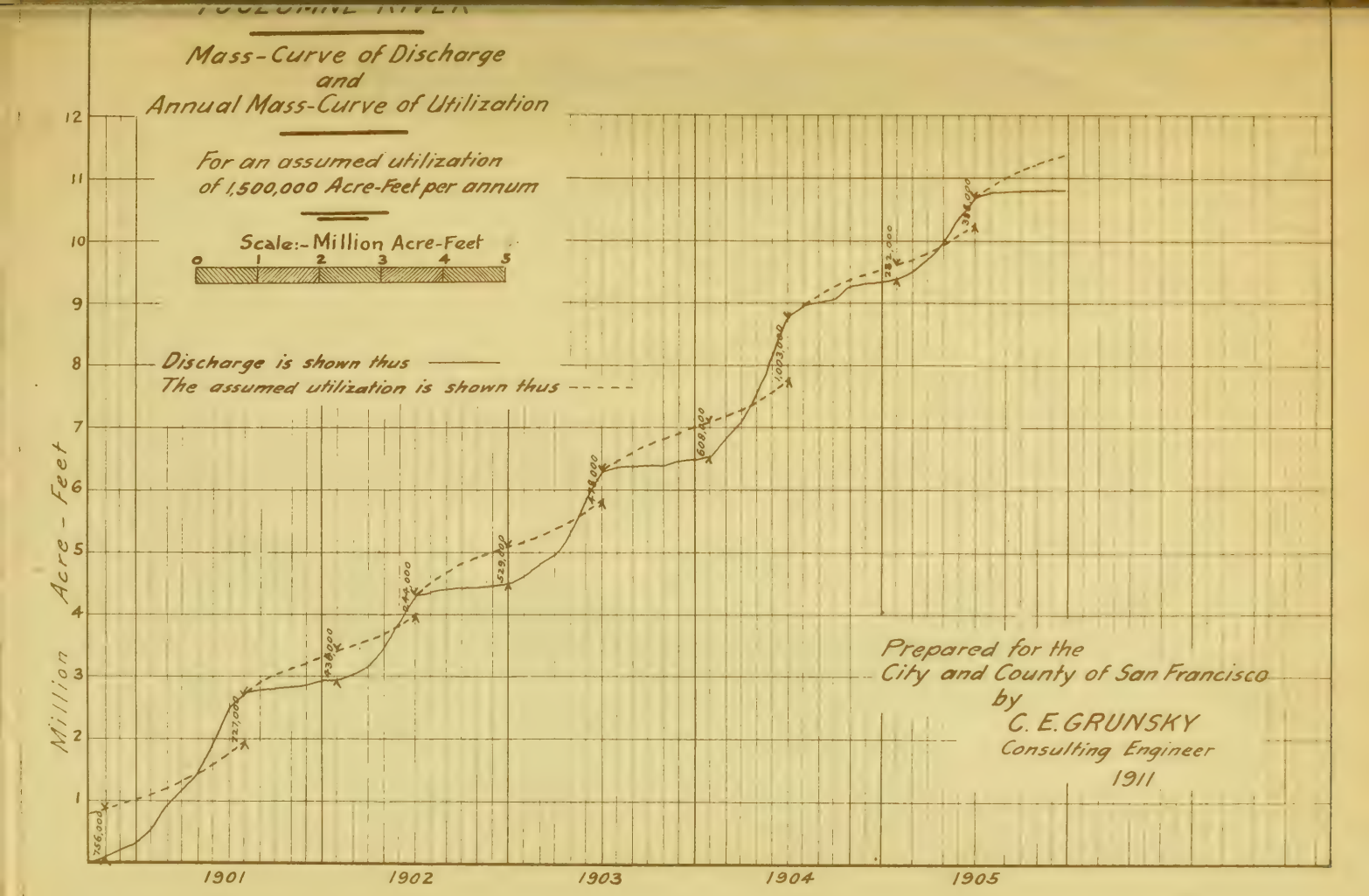

TUOLUMNE RIVER
Mass-Curve of Discharge
and
Annual Mass-Curve of Utilization
For an assumed utilization
of 1,500,000 Acre-Feet per annum
Scale:- Million Acre-Feet
0 1 2 3 4 5
Discharge is shown thus
The assumed utilization is shown thus
Million Acre-Feet
1 2 3 4 5 6 7 8 9 10 11 12
1901 1902 1903 1904 1905
266,000
727,000
1,030,000
1,444,000
1,529,000
1,744,000
1,809,000
2,283,000
2,744,000
Prepared for the
City and County of San Francisco
by
C. E. GRUNSKY
Consulting Engineer
1911

Fig. 4.

TUOLUMNE RIVER

Mass-Curve of Discharge and Annual Mass-Curve of Utilization

for an assumed utilization of 1,600,000 Acre-Feet per annum

Scale - Million Acre Feet

0 1 2 3 4 5

Discharge is shown thus ——

The assumed utilization is shown thus - - - -

Millions of Acre-Feet

13 12 11 10 9 8 7 6 5 4 3 2 1

1906 1907 1908 1909 1910

Prepared for the City and County of San Francisco by E. E. GRUNSKY Consulting Engineer 1910

TABLE V.

TUOLUMNE RIVER.

The draft upon storage and the surplus or deficiency of supply at stated periods. Effective storage capacity in adequate amount is assumed to be available.

For a Utilization of 1,500,000 acre feet per annum.

Year	Month	The required Storage	Month	Surplus or Deficiency--Acre Feet
1879-80	Mar.1880	730,000	July 1880	1,013,000
1880-81	Nov.1880	374,000	June 1881	708,000
1881-82	Feb. 1882	660,000	June 1882	66,000
1882-83	Mar.1883	565,000	June 1883	103,000
1883-84	Feb.1884	680,000	July 1884	758,000
1896-97	Nov.1896	835,000	June 1897	1,037,000
1897-98	Mar.1898	546,000	May 1898	-330,000
1898-99	Feb. 1899	1,159,000	June 1899	-259,000
1899-1900	Oct.1899	963,000	June 1900	205,000
1900-01	Oct.1900	756,000	July 1901	1,111,000
1901-02	Jan.1902	436,000	June 1902	344,000
1902-03	Dec.1902	529,000	June 1903	478,000
1903-04	Jan.1904	608,000	June 1904	1,003,000
1904-05	Jan.1905	236,000	June 1905	388,000
1905-06	Dec.1905	637,000	July 1906	1,779,000
1906-07	Dec.1906	258,000	July 1907	2,258,000
1907-08	Feb. 1908	365,000	June 1908	-176,000
1908-09	Dec.1908	752,000	July 1909	1,030,000
1909-10	Oct.1909	295,000	June 1910	738,000

With ample reservoir capacity and the assumed utilization of 1,500,000 acre feet per year, surplus water of the Tuolumne River would have run to waste during the years for which discharge records are available as follows:

For the period 1879 to 1884:-

In 1880 from, May,June and July	1,012,000	acre Feet
In 1881 " March to June	708,000	" "
In 1882 in June	66,000	" "
In 1883 in June	106,000	" "
In 1884 in May,June and July	758,000	" "

For the period 1895 to 1910:-

In 1897 in May,June and July	1,037,000	" "
In 1900 in May,June and July	205,000	" "
In 1901 in May,June and July	1,111,000	" "
In 1902 in June	244,000	" "
In 1903 in May and June	478,000	" "
In 1904 in April,May and June	1,003,000	" "
In 1905 in May and June	388,000	" "
In 1906 in April,May,June and July	1,779,000	" "
In 1907 from Feb.to July(Incl.)	2,258,000	" "
In 1909 in May,June and July	1,030,000	" "
In 1910 from Jan. to June (Incl.)	738,000	" "

By diagram, Fig. 5 on the folder, the discharge of Tuolumne River by months is graphically represented. In this diagram the mean monthly flow is compared with the assumed monthly utilization, and by appropriate shading of areas, the amount of water required from storage and the amount available to fill the depleted reservoirs is made apparent to the eye. It is of course only then strictly correct to use the mean monthly rates of discharge in place of the momentary flow of the river in the preparation of such a diagram, when the available reservoir capacity is fully adequate to completely regulate the discharge. But as this is assumed to be nearly true for the utilization lines shown,

the relative magnitude of the shaded areas may be accepted as substantially correct.

A utilization of 1,500,000 acre feet per year, as already stated, has been made the basis of the diagram and the figures in the foregoing table. Any other amount nearly up to the mean annual discharge of about 2,000,000 acre feet might have been used for the purpose of illustrating the large storage that could be made useful if available, in regulating the stream flow. But the cases are so rare in which on a large stream nearly full utilization of discharge can be realized that an efficiency factor which is frequently within reach has been preferred for use in this illustration, which, after all, is merely intended as a demonstration of the fact that the non-development of storage in the Hetch-Hetchy Valley would be a permanent loss which can not be compensated with storage elsewhere.

The column, in Table V. "Surplus or Deficiency" shows that the discharge of the river is ample to supply water for storage up to the maximum indicated draft upon storage of 1,160,000 acre feet with more or less surplus in 16 out of 19 years for which records were available when the above table was prepared.

The assumption of a maximum utilization of 1,500,000 acre feet per year, predicated on the availability of ample storage sites, is not therefore unreasonable. For any deficiency of effective storage below

1,160,000 acre feet the actual possible utilization will be reduced.

By an analysis, for which the figures need not be given in detail, it can be shown that if the effective storage capacity of all possible reservoirs were 500,000 acre feet the annual utilization without any shortages would be about 1,100,000 acre feet. The efficiency factor for the river would drop down toward 50 per cent.

Throughout the foregoing discussion the possible aggregate storage indicated by surveys of the reservoir sites is accepted as being all available for effective use; that is to say, it is assumed to be all so located that the tributary watershed will periodically effect complete replenishment. This is a condition that can probably not be realized. The capacities of the several reservoirs stand in all manner of relations to the runoff from their watersheds. Taken as a whole, therefore, they should not be considered effective up to their aggregate capacities. This fact is cited merely to emphasize the conclusion that there is a shortage of available storage sites on the Tuolumne River, and that the storage capacity of Hetch Hetchy Valley can not be offset by storage in any other site. Failure to develop Hetch Hetchy Valley to its utmost capacity as a reservoir would be a grevious economic mistake.

It is needless to attempt, with the incomplete data now available, to outline any comprehensive project for the highest feasible development of

the water resources afforded by the Tuolumne River system. It will suffice to have pointed out that so long as actual reservoirs constructed in the course of time fall short of an aggregate capacity of 1,160,000 acre feet there will be material under-development of the water resources of Tuolumne River.

Of course the desirable storage capacity here determined is based upon certain assumptions relating to the ultimate water requirements which can not be foretold with perfect accuracy. Had the irrigation requirement been assumed larger in proportion to the water requirement for other purposes, then the departure of the utilization curve from a straight line would have been increased and a slightly less amount of storage would have been shown to be necessary. On the other hand, if the irrigation requirement is overestimated then the utilization curve would more ~~clearly~~ nearly approximate a straight line and a somewhat larger amount of storage would be indicated as necessary for a reasonably full utilization of the water of Tuolumne River.

It is to be noted too that the location of Hetch-Hetchy Valley as an intercepter of the runoff from some of the most productive portio s of the high mountain watershed of Tuolumne River is ideal. The configuration of the valley is favorable for water storage and the cost of storage is reasonable.

The substitution of a lake encompassed by majestic cliffs, for the present meadow will add to the scenic beauty of the Tuolumne gorge; the utilization of the Tuolumne River as a source of water by so important a community as San Francisco will insure the conservation of the tributary watershed as a collecting ground for water, in public ownership, open always to the enjoyment of the mountain tourist; the withdrawal from use of the meadow lands which are to be deeply flooded is not a matter of vital importance to any interests and the storage of water in the valley would conserve for the highest possible use a large portion of the river water which would otherwise flow uselessly to the sea, a menace from time to time to riprarian properties which adequate reservoirs would in large measure serve to reduce.

In the absence of any weighty reasons for a permanent withdrawal of Hetch-Hetchy Valley from use as a storage reservoir no other conclusion can be reached under these circumstances than that some time it will be so used. The time when water is there stored may be delayed, but the need of storage space for water all of which will some day be in demand is so obvious that no other outcome seems possible.

San Francisco has proceeded in good faith to select the Tuolumne River as its future main

source of water. The City took proper steps to secure for its inhabitants the legal right to water from this source. It not only did this, but asked for the necessary right-of-way over the public domain in the form prescribed by law and by Department regulations, and under the foregoing demonstration there should be no thought of any revocation of the permit already granted to San Francisco, but the day should be hastened when the storage of water in the valley is made an accomplished fact.

It is believed that no impartial expert can reach any conclusion other than, that, under full development of the storage possibilities in the Hetch-Hetchy Valley there would be for many years a surplus over and above San Francisco's needs which could be liberated for the benefit of the irrigators, who under conditions of natural flow, not modified by storage, will occasionally be short of water. A suitable agreement for the liberation of such surplus water as may be determined to be available from year to year would certainly be of measurable benefit to the two irrigation districts. This benefit will be greater, relatively, in the near future than later when San Francisco's needs for water have increased and when the districts are better able financially to make large expenditures for storage in sites of their own selection.

The portion of the watershed of the Tuolumne River, a part of whose runoff is to be used to meet San Francisco's requirements, is by reason of altitude and

topographic and climatic conditions admirably suited to be made the source of the City's water. Against this source is its remoreness. The aqueduct from the point of diversion from the river to San Francisco, assuming that no intermediate point, such as Crystal Springs reservoir be made the pipe line terminal, will have a length of about 175 miles.

The diversion works on Tuolumne River will be about 140 miles in an air line from San Francisco. It would, of course, be preferable to have the mountain source of water nearer, but in this respect the Tuolumne River is quite as favorably located as any other Sierra Nevada project with which it can be compared.

If San Francisco does not develop the Hetch-Hetchy storage site, the time will come when for some other use, as for the water supply of valley cities or for power purposes and in some measure, perhaps, for irrigation extension, this valley will be converted into a reservoir. This is an assumption which probably all persons who want water from the Tuolumne River to reach the bay region, as well as all persons interested in the full development of the region drained by the Tuolumne, as well as that bordering both banks of the lower reaches of the river, will heartily concur in.

If, therefore, San Francisco uses Hetch-Hetchy Valley the only complaint that might fairly be made by local interests would be that some of this river's water would be used to promote development in a region at considerable distance from the locality where the water

originates and that to this extent opportunity for development is removed from the interior of the State to the population center at San Francisco Bay.

In the development of natural resources "the greatest good to the greatest number" is the policy which should prevail. The densely populated bay slopes of San Francisco are within the same drainage basin of which the Tuolumne watershed is a part. But San Francisco does not contain within her own area any adequate source of water. By reason of local topographic, geographic, soil and climate conditions comparatively large areas of the Coast Range near San Francisco have already been brought under contribution to meet the city's growing needs for water. The control and absolute ownership of large areas of land has become necessary to safeguard the quality of the water. This is a feature which becomes the more objectionable and burdensome the nearer the source of water is to the center of population. For a development of about 35,000,000 gallons of water, as the capacity of the Spring Valley Water Works was rated some years ago, the area of land in the absolute ownership of the water company was then estimated at over 20,000 acres in San Mateo County and about 23,000 acres in Alameda and Santa Clara Counties.

For the development of more water more land has since been acquired. The total area now owned within a radius of about 50 miles from San Francisco, not

including properties lying beyond the bay watershed nor lots and small city tracts, is over 80,000 acres.

The growing cities on and near San Francisco Bay are constantly requiring more water and it is easy to make a forecast of the population whose needs would be as great as the total amount of water which can be made available from near-by sources. With the further development of these sources will come further control and ownership of watersheds until the withdrawal of near-by areas from human occupancy becomes too onerous and burdensome.

It goes without saying that a collecting ground for waters for domestic use, other things being equal, becomes more desirable and more available the more inaccessible it is and the less it is adapted to human habitation and to human activities. The collecting ground for water for large cities is therefore usually remote from rather than near great centers of population.

If the resources must be withdrawn from any region for the benefit of the great centers of population, it is better that this be from a region of least development and of least ultimate promise. From this standpoint it appears clear that it is much better for the main source of water for the bay cities to be in the high Sierras than within the counties lying close about the bay.

Under the present system the Spring Valley Water Company, under the necessity of protecting the quality of the water, has acquired its holdings in the neighboring counties. It is still extending these holdings and

is thereby exerting a potent restraining influence upon the development and prosperity of areas otherwise full of promise.

San Mateo County, though collecting taxes on the water company's property, which the San Francisco rate payers contribute indirectly, loses the benefit that would result from the manifold occupations of the inhabitants of some 20,000 acres of land. This area is held in absolute ownership in part for the works of the water supply system, but mainly for the purpose of protecting the quality of the water.

In Alameda County the Sunol, San Antonio and Caraveras valleys can not become centers of general activity--they are required for water storage or filtration purposes and the tributary areas about and above them must in large part be kept depopulated in order that the water developed by storage or otherwise may be wholesome.

The withdrawal of resources naturally tributary to such regions for a higher use than that to which they would otherwise be applied has been an essential requirement to meet the needs of San Francisco, but the time has come when the principle should be recognized that such withdrawal should not necessarily be extended within the region close to the bay. It should be recognized too that wherever at any remote point, as in the Sierra Nevada, some water is diverted or some storage site is utilized for the municipal water works, there will in some measure be

decreased the natural, for the most part undeveloped, resources which could ultimately benefit some other part of the State.

It is therefore a reasonable assumption that no source of supply can be found from which San Francisco could take water without in some measure affecting other interests. The cities and lands upon the east side of San Francisco Bay, to which Alameda Creek may be considered more directly tributary than to San Francisco, are deprived of the ultimate use of the water of this creek to the extent that San Francisco uses its water. The diversion of water from Uvas and Llagas Creeks, which flow southward toward Gilroy, and more particularly the diversion of water from Coyote Creek and from the gravels of Coyote Valley, as proposed by the Bay Cities Water Company, which made an offer of these waters to San Francisco some years ago, was viewed with alarm by the people of Santa Clara Valley. A diversion of water from the Stanislaus River, the Mokelumne River, or the Merced River would no doubt meet with quite as strenuous objections as was offered by the irrigation districts along the Tuolumne River to the taking of any water from that stream by San Francisco. And yet such objections do not ordinarily originate from a conviction that there would be any immediate damage to local interests, but from the belief that in some way there would be an interference with the ultimate prosperity of the local communities.

It is not to be hoped, therefore, that any Sierra Nevada project of water supply for San Francisco can be suggested which will not meet with objections of this character.

San Francisco in selecting Tuolumne River as a source of supply reached the conclusion deliberately that this river was the best source of wholesome water from which to obtain the large volume needed. The river, as has been explained, carries to the sea much water which so long as Hetch-Hetchy Valley is withheld from use as a storage basin must go to waste. The City does not desire to use a second rate water so long as the best is witnin reach. It can not obtain from Lake Eleanor all of the water over which it should have control. Water from other areas must be added. The original application for rights-of-way were made with the distinct purpose of developing first the Hetch-Hetchy supply and in later years adding Lake Eleanor. The permit under which San Francisco is now operating has reversed the order of development to the disadvantage of the City. However in either case both sides are necessary for the ideal project which will safeguard the adequacy of a supply of good water for a long time in the future. One hundred years is a short time in the life of a city and it is reasonable for the City to look forward to the conditions which will then prevail and to so plan its work that future generations will be spared embarassment in this matter.

To the question - How will Turlock and Modesto Irrigation Districts, which have a combined area

of 857,530 acres be affected by the use of Hetch-Hetchy Valley as a storage site by San Francisco?-- the following reply may be made.

If Hetch Hetchy is not used as a reservoir by San Francisco, then it must be assumed that the valley will never be converted into a reservoir for any use. On any other assumption the right would have to be conceded to San Francisco to develop storage there as soon as needed. On the assumption of non-use, as has already been shown, a part of the water resources of the river are permanently lost. The irrigation districts in such a case forego any advantage that might otherwise accrue from the liberation of stored water, now absolutely waste. If on the other hand the reservoir is constructed by San Francisco the City will for one quarter to one half a century, depending upon the height of the dam and storage capacity, and perhaps even for a longer time, have surplus water on hand which may be liberated during the periods when it will be of greatest benefit to the irrigation districts. There is in this case a probability of material benefit to the districts. This is to be compared with no added benefit so far as conservation of their resources is concerned if Hetch-Hetchy be never used as a reservoir. San Francisco proposes, in other words, to store in Hetch-Hetchy Valley some of the water which will continue to go to waste, and remain unavailable for the districts for lack of adequate storage facilities.

It may be urged, of course, that future administrations are not bound to respect any action by present administrations looking toward the withholding of Hetch-Hetchy Valley from use as a reservoir and that if not used at an early day by San Francisco that at some subsequent period a right to use the valley may be granted either to the districts or to private interests that would use the water with greater benefit to the districts than San Francisco could do. It must be remembered, however, that San Francisco has already acquired a large part of the reservoir area and holds a title thereto which enables the City to maintain for all time its first right to the use of the reservoir site. The use to which San Francisco desires to put the reservoir is, moreover, as high as any use to which it can be put.

CHAPTER II.

CRYSTAL SPRINGS RESERVOIR-WATER UNACCOUNTED FOR.

MEMORANDUM

Relating to Crystal Springs Reservoir.
Water Unaccounted for.

By C. E. Grunsky, Consulting Engineer.
1911.

As a result of a study of the water productiveness of the area tributary to Crystal Springs reservoir, the fact has become apparent that a certain amount of the water which flows into the reservoir remains unaccounted for. It has long been known that the drainage basin of this reservoir, in the light of its aggregate water production, must be classed as a watershed of low efficiency, but opportunity has never before been presented for demonstrating that after taking into account the draft upon the reservoir, the gain or loss in storage and evaporation, there still remains an unexplained cause of depletion of sufficient moment to be worthy of further exhaustive investigation.

Two periods have been selected as a basis for the study, 1894 to 1898 and 1902 to 1908. The latter was selected to trace, if possible, any material effect of the earthquake of 1906.

The draft upon the reservoir is noted from the records maintained by the Water Company. It is based upon the measurements of the water where it flows from the Crystal Springs pipe line into the University Mound reservoir with a deduction of the water pumped into the Crystal Springs pipe by the Belmont pumps and with an addition of

the water pumped by the Crystal Springs pumps, as far some months in 1893, from the Crystal Springs reservoir into the San Andres reservoir, and an addition of the water pumped as in June 1905 by the Millbrae pumps from the Crystal Springs pipe into the San Andres pipe.

For the first period the daily records were used; for the second period the monthly totals were taken from the Water Company's records.

The loss of water from the reservoir by evaporation was based upon the average area during each month, to which a rate was applied as ascertained from an evaporation curve and the monthly mean temperature at San Mateo.

For this determination of evaporation it was assumed that the monthly mean temperature at San Mateo would be at least as high as the monthly mean at the reservoir, and that for correspondingly monthly temperatures the rate of evaporation would be as high as in the dry climate of the San Joaquin Valley, where the observations were made on which the evaporation curve is based. If there is error in these assumptions it is probably in the direction of an overestimate of evaporation. An assumption of lower temperature at the reservoir than at San Mateo would reduce the approximated rate. Any allowance for greater humidity at the reser-

voir than in the San Joaquin Valley or for more cloudy and rainy days would likewise reduce this rate.

It does not, therefore, appear probable that the excessive depletion of the reservoir can be explained by assuming an underestimate in these rates.

The mean annual evaporation loss estimated from the average monthly means of temperature at San Mateo (from 1894 to 1908) is shown in Table VI in which evaporation at Kingsburg, Fresno County, from an open water surface is compared with the assumed evaporation at San Mateo.

TABLE VI.

Evaporation at Kingsburg, Fresno County and at San Mateo.

Month	Fresno Normal Mean Monthly Temp.	Kingsburg Evaporation As observed: ft. in 24 hours	Kingsburg Evaporation From Curve Ft. in 24 Hours	San Mateo 1894 - 1908 Average Mean Monthly Temp.	San Mateo 1894 - 1908 Evaporation ft. in 24 Hours
January	45.3	.0028	.0026	50.4	.0039
February	50.2	.0035	.0038	52.6	.0047
March	54.4	.0068	.0053	54.8	.0055
April	60.8	.0077	.0082	59.0	.0073
May	67.4	.0113	.0127	63.0	.0095
June	74.1	.0185	.0179	68.0	.0131
July	82.1	.0285	.0245	68.7	.0136
August	81.0	.0244	.0236	68.9	.0133
September	73.8	.0186	.0176	65.9	.0116
October	64.2	.0105	.0103	61.9	.0089
November	54.6	.0059	.0054	56.8	.0063
December	47.0	.0038	.0030	50.8	.0038
Annual Total Evap. Ft.		4.05	4.05		3.05

The records on which the curve of evaporation is based cover a period of four years, 1881 to 1885. The observations were in charge of the writer and were made under direction of Mr. William Ham. Hall, at that time State Engineer of California. They were published in "Physical Data and Statistics" State Engineer, 1886. Two pans were used, one floating in Kings River at Kingsburg, the other for the first three months on a bridge and thereafter on the ground with sand banked around its sides to the height of the water surface. The pans were of galvanized iron 3 feet square, about 15 inches deep and the water surface was kept at about 5 inches below the tops of the sides. A peg tapering to a point rose in the center of each pan to the water surface. The observor was required to replenish the evaporated water from time to time, using a gaged vessel the contents of which represented 0.01 feet of water depth. Observations of temperature were made daily. The water was replenished daily in the warm months and in winter whenever it had fallen about $\frac{1}{4}$ inch below the top of the peg. The evaporated loss was always replenished when the weather looked threatening. After a rain the excess water was dipped out, a record of the water taken out being made.

The purpose of the Kingsburg observations was not to establish any law governing the momentary rate of evaportion, but to ascertain the probable annual total from a water surface in the San Joaquin Valley. The

four year record shows 3.85 feet as the average depth of water evaporating from the pan in the river and 4.96 feet as the depth of water evaporating from the pan on the ground.

It is believed that the evaporation measured from the pan in the river at Kingsburg was somewhat less than would have occurred from a large body of open water, mainly for the reason that some protection was afforded to the pan by the high river banks, a fringe of low trees and a nearby bridge, and for the further reason that the river temperature was probably a little below what would have been the temperature of an open body of water. The pan on the ground on the other hand undoubtedly showed evaporation in excess of what would have taken place from a water surface of large extent, particularly for the reason that the water in this pan was warmer than the surface of any large body of water would have been. The measured values as noted from month to month have, therefore, been combined to approximate the probable evaporation from an open body of water. The combination has been made by giving the record of the pan floating in the river triple weight.

The results of this combination from month to month, averaged for the four years, is shown in the foregoing table. In the column with the heading "From curve" are shown the probable average monthly evaporation rates.

The mean monthly temperature as the table shows are from Fresno records. These were obtained for a series of years, which, according to the writer's recollection, did not coincide with the four years covered by the evaporation record, but covered a long enough period to be considered a fair approximation of the normals.

When the evaporation rates from month to month were compared with the mean temperature of the months at Kingsburg and similar comparison was made for other evaporation records, as at Lee Bridge near London(1860-1873) 14 years by Mr. Chas. Greaves C.E. (Proc.Inct. C.E. Vol.XLV) and as at Boston 6 years between 1876 and 1886, by Desmond Fitzgerald(Transactions Am.Soc.C.E.1886), it became apparent to the writer that the average rate of evaporation during 30 day periods closely follows the mean temperatures of these periods. This seems reasonable when it is considered that in some measure the mean water surface temperatures of open water bodies will rise or fall with the mean monthly temperatures of the air and that under generally similar climatic conditions the wind in different localities may be assumed to have equal effect in the long run upon the evaporation. In other words, any relatively greater or less wind movement than at Kingsburg is ignored in applying the California curve.

That the important factor controlling the rate of evaporation is temperature, and that relative humidity of the air and wind movements are of minor importance

When considering the evaporation from open bodies of water of large extent, has long been known and there is no doubt that curves similar to the one based on the Kingsburg records could be constructed for application in other parts of the country. It is believed that the California curve will give substantially correct results for any point on the Pacific slope or in the arid regions of the country having climatic conditions similar to those at Kingsburg. The fact is not to be overlooked, however, that the curve gives only average monthly rates of evaporation for mean monthly temperatures and that it can not be used to determine from a mean daily temperature a daily rate for single days.

The California evaporation curve as established by the Kingsburg records is shown in Fig. 6.

Before proceeding further a brief reference to the results of the study of summer inflow into the two other peninsula reservoirs of the Spring Valley Water System may be noted.

In estimating the inflow of water into the Pilarcitos and San Andres reservoirs(combined) note was taken of the monthly gain or loss in storage. To the gain in storage there was added the draft upon the reservoir through the main pipe line during the month and the evaporation loss. There was deducted the water delivered into the San Andres reservoir by the Crystal Springs pumps. There was no correction made for rain falling upon the water surface of the reservoirs.

CALIFORNIA EVAPORATION CURVE

showing the relation
of the monthly mean rate of evaporation
& the monthly mean temperature

The evaporation loss from these reservoirs was estimated, as in the case of Crystal Springs, by applying to the monthly mean water surface area of the two reservoirs the rate of evaporation indicated for the monthly mean temperature at San Mateo by the California evaporation curve.

The results of this study for three selected years are presented in tabular and in diagramatic form in a separate Memorandum relating to the "Runoff from areas tributary to Pilarcitos and San Andres Reservoirs." This runoff includes the rain upon the water surface of the reservoirs. The selected years are 1894-95, 1896-97 and 1897-98 of which the first is a year of copious rain, the second is a year of about normal rainfall conditions, and the third is a year of light rainfall.

For periods during which water was being wasted, i. e., during which water reached the reservoirs or the conduits leading to the reservoirs in excess of capacity, there has been some approximation.

Reference is here made to these tables and diagrams of water production in order to show that throughout each of the three years and every month in each year there has been some inflow. For the three months of least productiveness, July, August and September, the inflow from the 12.8 square miles of tributary watershed has averaged 1.14 million gallons, or about 90,000 gallons per square mile.

If it be now assumed that too low a rate of evaporation has been applied and some higher rate is introduced into the analysis, there will be a corresponding increase of inflow indicated. This fact is pertinent in the discussion of the unexplained depletion of the storage in Crystal Springs reservoir, because if the water not accounted for has evaporated, the assumed evaporation rate would have to be materially increased, and the higher evaporation rate would then have to be applied also to the Pilarcitos and San Andres systems.

That there is some runoff during the rainless summer months from the Coast range areas which are tributary to the peninsula reservoirs, was known without the San Andres and Pilarcitos demonstrations. Such runoff is seen at times in the creeks and in springs. Without question there is some inflow too into Crystal Springs reservoir during the summer even though the same can not all me measured as visible flow. It is probable,however, that, per square mile of watershed, the summer yield is less than at Pilarcitos and San Andres because the normal fall of rain is less. It may be assumed as a crude approximation that the summer flow from springs will be proportional to the annual rain. On this basis if the Pilarcitos and San Andres areas with a normal rain of about 48 inches ordinarily produce 1,140,000 gallons of water per day in summer, or 90,000 gallons per day per square mile, the watershed of Crystal Springs, with a normal rain of about 36 inches should produce about 70,000 gallons

per day per square mile during the three months, July, August and September. This is about 1.53 million gallons per day for the 23.5 miles of watershed and some such amount should be added to the quantities noted in Tables VII to X when estimating the unexplained loss.

In these tables the draft upon the Crystal Springs reservoir must be understood to mean only water delivered from the reservoir in San Francisco. There is an additional draft to be taken into account amounting to about 400,000 gallons per day, being the water taken from the pipe line above the point of measurement, for use in and near San Mateo and there is also a correction to be applied for slip in the pumps. If the correction for slip at the Belmont pumps is estimated at 2 per cent it might be introduced into the calculation at about 100,000 gallons per day in 1894, 1895 and 1897; about 60,000 gallons in 1896 and in 1898; about 200,000 gallons per day in 1902, and about 350,000 gallons per day thereafter. Some correction should be applied too to the recorded quantities of water pumped by the Crystal Springs pump and by the pumps at Millbrae.

The main correction for slip is that however in the Belmont pumps. This, together with the water taken from the pipe line, is a partial offset from 450,000 to 750,000 gallons per day to the 1,580,000 gallons which may reach the reservoir from its watershed during the summer months.

In view of all these facts the water noted in Tables IX, X and XII as water to be accounted for is probably somewhat under, rather than over, the amount which requires explanation.

TABLE VII

Crystal Springs Reservoir
Water Production May to November 1894 to 1898

Month	Rain Inches	Res. area acres	Million Gallons Per Day				
			Draft# D	Evap. E.	C.or L. G	Rain R.	X
1894						1.55	
May	1.38	1280	5.65	4.85	- 7.03	1.55	0.73
June	.08	1270	5.87	4.85	-12.43	.09	-2.00
July	0	1245	5.85	5.30	-14.30	0	-3.35
Aug.	0	1230	6.35	5.21	-14.90	0	-3.34
Sept.	1.81	1200	6.95	5.53	-12.40	1.97	-2.30
Oct.	4.68	1190	5.36	3.52	- 7.13	2.98	-0.94
Nov.	1.51	1180	3.73	3.63	-10.97	1.61	-1.35
1895							
May	0.92	1270	9.74	3.97	-13.3	1.07	-0.65
June	0	1265	10.05	4.50	-13.23	0	-3.38(*)
July	0.03	1240	7.87	4.50	-1 .81	.03	-5.47
Aug.	.03	1210	3.87	4.05	- .66	.03	-1.7
Sept.	.51	1200	3.89	4.3	-10.70	.55	-2.7
Oct.	.30	1190	4.19	3.41	- 8.65	.33	-1.38
Nov.	1.75	1180	4.00	3.34	- 7.77	1.87	- 3.30
1896							
May	1.09	1270	11.83	3.91	- 5.35	1.35	4.34
June	.01	1260	6.83	4.43	-13.03	.01	-2.86
July	0	1230	4.51	4.33	-11.10	0	-3.10
Aug.	.21	1210	3.73	3.98	-14.04	.22	-7.31
Sept.	1.05	1190	3.62	4.38	-14.23	1.13	-7.06
Oct.	1.65	1170	3.43	3.16	- 7.48	1.69	-3.58
Nov.	0.91	1165	3.58	2.33	- 3.10	7.33	.61

Incomplete draft as explained in the text.
R is the rain which falls upon the water surface of the reservoir.
$X = D + E + G - R$
When there is a decrease of storage instead of gain G will be negative.

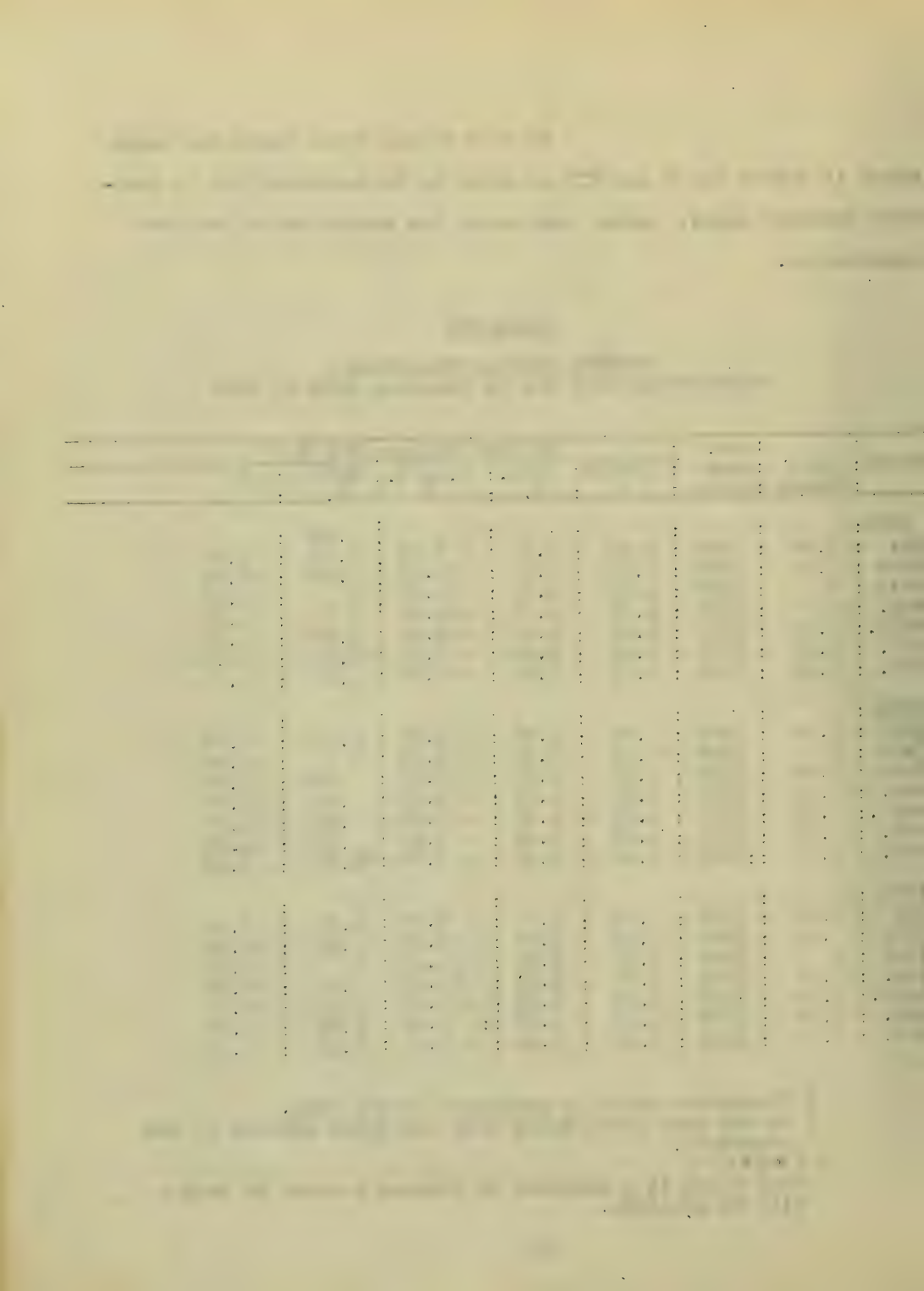


TABLE VII. (Continued)

Month	Rain Inches	Res. Area Acres	Million Gallons per day: Draft D.	Evap. E.	G. of L. G.	Rain R.	X
1897							
May	.11	1280	11.45	4.80	-16.47	.12	-0.61
June	.08	1350	13.36	5.59	-24.90	.09	-6.04
July	0	1315	14.50	5.99	-25.77	0	-5.28
Aug	0	1185	9.49	4.53	-17.48	0	-3.46
Sept	0	1160	8.32	4.54	-16.03	0	-3.17
Oct	2.69	1125	7.47	3.00	-11.26	2.66	-3.45
Nov	1.35	1110	6.94	1.84	-10.40	1.31	-2.93
1898							
May	3.19	1030	13.23	3.92	-15.65	1.99	-1.49
June	.43	995	14.12	4.87	-20.60	.38	-1.99
July	0	970	14.54	4.17	-23.03	0	-4.32
Aug	0	940	14.82	4.88	-25.77	0	-6.07
Sept	1.69	890	7.03	3.17	-14.80	1.36	-5.96
Oct	1.02	870	5.47	2.82	-12.48	.80	-4.99
Nov	.81	850	13.41	1.47	-20.68	.62	-6.42#

During Nov. 1898 the Belmont pimps, the Millbrae pumps, and the Crystal Springs pumps were all in service.

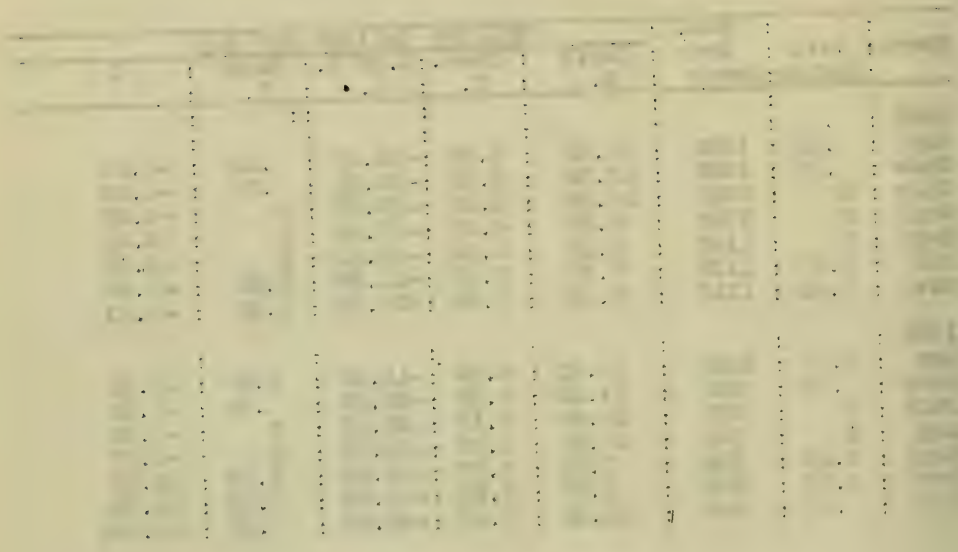


TABLE VIII

Crystal Springs Reservoir
Water Production from May to November 1902 to 1908

Month	Rain Inches	Res. Area Acres	Million Gallons per day: Draft # D.	Evap. E.	G. or L. G.	Rain R.	X
1902							
May	1.19	680	3.63	1.84	- 6.98	.71	-2.22
June	.13	675	5.35	3.78	-12.23	.07	-4.17
July	0	645	5.18	3.32	-11.50	0	-3.40
Aug	0	630	5.17	3.53	-11.95	0	-4.36
Sept	0	595	6.21	3.43	-11.03	0	-2.39
Oct	2.77	570	5.51	1.71	- 8.25	1.39	-2.42
Nov	4.39	560	2.33	.94	- 5.13	2.22	-4.08
1903							
May	0	755	0.45	1.97	- 4.20	0	-1.78
June	0	750	0	3.50	- 4.43	0	- .93
July	0	735	0	2.91	- 6.08	0	-3.17
Aug	0	720	3.53	2.81	- 9.21	0	-2.87
Sept	0	705	6.11	2.95	-10.67	0	-1.63
Oct	2.77	685	6.70	2.15	- 9.95	1.66	-2.76
Nov	9.23	680	3.89	1.35	- 5.87	5.70	-5.41
1904							
May	.41	970	0.73	4.40	- 8.87	.36	1.90
June	0	960	0.85	5.00	-7.03	0	-1.18
July	.02	945	0.71	4.00	- 6.65	.02	-1.96
Aug	.04	940	3.05	2.54	- 8.15	.03	-2.59
Sept	5.14	930	6.20	4.65	- 6.00	4.30	- .84
Oct	4.21	925	6.09	2.80	- 1.71	3.41	-3.97
Nov	1.50	915	7.85	2.12	- 7.27	1.24	-1.46

Incomplete draft as explained in the text.

R is the rain which falls on the water surface of the reservoir

$X = D + E + G - R$

When there is a decrease of storage instead of a gain G will be negative.

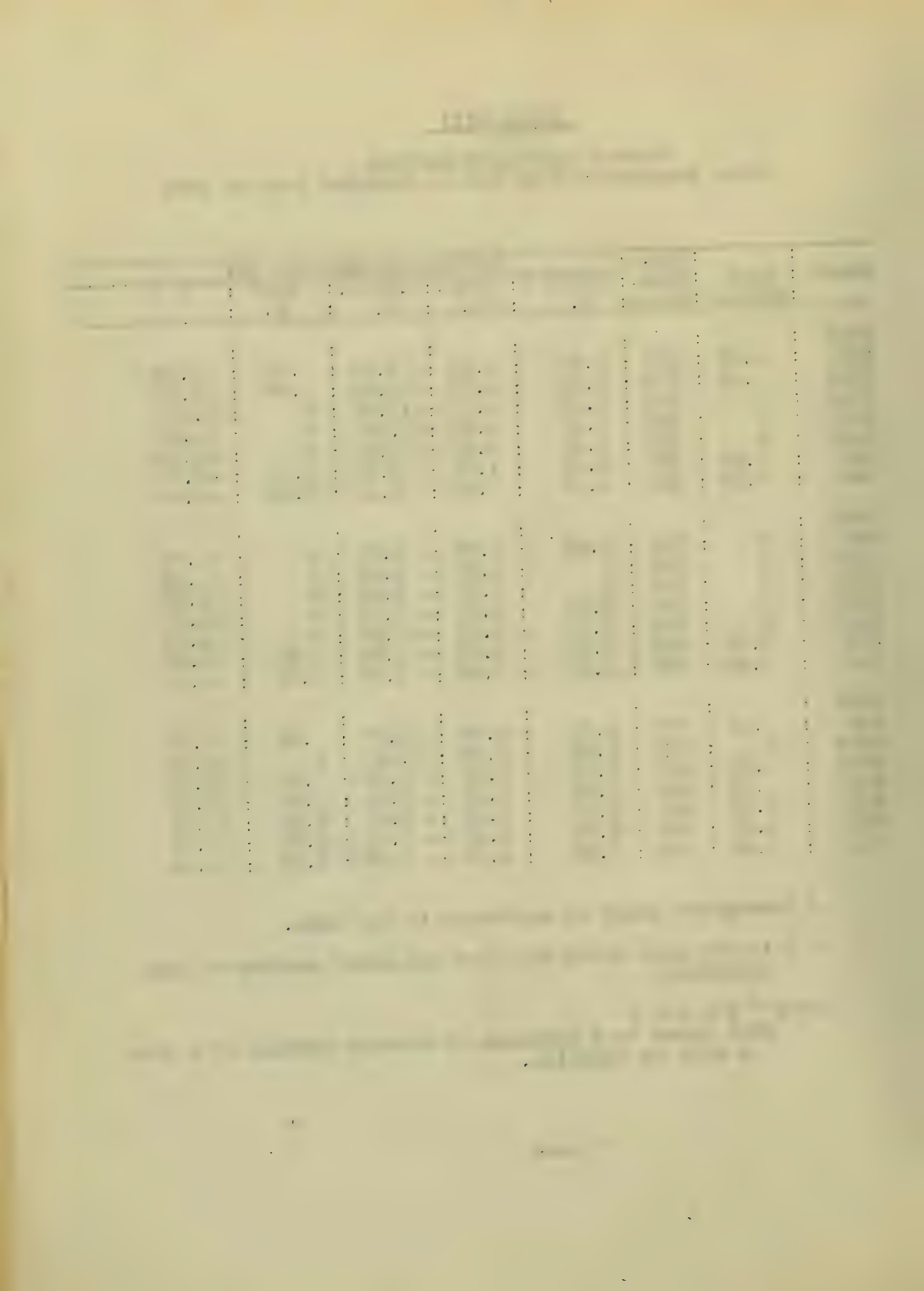


TABLE VIII (Continued)

Month	Rain Inches	Res. Area Acres	Million Gallons per day: Draft D.	Evap. E.	G. or L. G	Rain R	X
1905							
May	3.15	980	13.75	2.82	- 1.26	3.71	13.60
June	0	960	4.14	2.54	- 6.76	0	.92
July	0	955	1.99	4.58	- 8.60	0	-2.03
Aug	0	940	4.01	3.71	- 9.55	0	- 1.83
Sept	0	920	8.08	3.60	-12.60	0	.92
Oct	0	900	9.93	3.79	-13.90	0	- 1.19
Nov	2.51	880	9.43	2.10	- 10.33	2.00	- .81
1906							
May	2.01	1060	2.61	3.31	-,3.39	1.87	.76
June	.42	1065	2.94	4.92	7.67	.41	- .22
July	0	1060	3.32	5.31	-10.02	0	- 1.39
Aug	0	1040	2.87	4.44	-16.20	0	- 6.89
Sept	.13	1010	3.05	4.09	-14.07	.12	- 7.05
Oct	.01	995	4.18	3.83	-10.38	.01	- 2.84
Nov	2.15	980	6.03	3.04	- 9.30	1.90	- 3.14
1907							
May	.35	1310	2.50	5.65	- 6.70	.40	.05
June	.80	1300	2.16	6.85	- 3.83	1.01	- 1.83
July	0	1290	3.21	5.50	-12.30	0	- 3.59
Aug	0	1265	3.42	5.02	-12.10	0	-3.36
Sept	0	1250	2.95	2.89	- 9.47	0	- 3.63
Oct	1.95	1240	3.51	3.19	-7.68	2.30	-3.38
Nov	.03	1230	2.01	2.60	- 8.73	.03	- 4.15
1908							
May	1.16	1310	2.39	3.68	- 8.15	1.33	- 3.41
June	0 0	1295	3.34	4.34	-11.30	0	- 3.62
July	.10	1270	3.69	5.92	-12.80	.11	-3.30
Aug	.02	1260	7.11	5.00	-16.20	.02	- 4.11
Sept	0	1235	8.29	4.87	-21.17	0	-3.01
Oct	1.13	1210	9.75	3.31	-13.60	1.20	- .74
Nov	2.11	1200	8.62	2.31	- 3.00	2.38	5.65

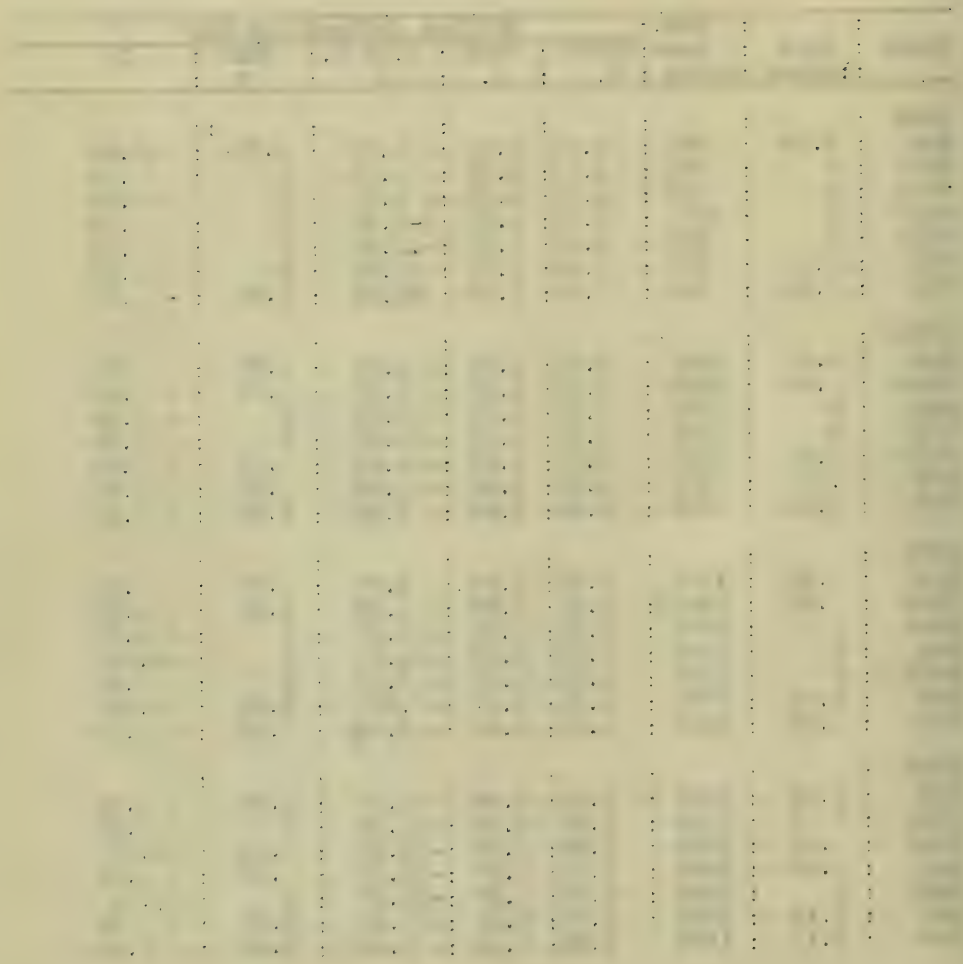


TABLE IX

Crystal Springs Reservoir.

Water to be accounted for by draft upon the pipe line, and by slip at pumps and by unexplained losses.

uary - 1894 - 1898 — Million Gallons per day

th	1894 Rain Inches	1894 To be Acc.for	1895 Rain Inches	1895 To be Ac.for	1896 Rain Inches	1896 To be Ac.for	1897 Rain Inches	1897 To be Ac.for	1898 Rain Inches	1898 To be Acc.for
	1.38	----	0.92	.85	1.99	----	.11	0.61	2.19	1.49
e	.08	2.00	0	3.68	.01	2.88	.08	6.04	.43	1.79
y	0	3.35	.03	5.47	0	2.26	0	5.28	0	4.32
	0	3.34	.03	1.79	.21	7.39	0	3.46	0	6.07
t	1.81	2.30	.51	2.97	1.05	7.06	0	3.17	1.69	5.96
	4.68	.94	.30	1.38	1.65	3.58	2.69	3.45	1.03	4.99
	1.51	1.23			6.99	----	1.35	2.93	.81	6.42

TABLE X

Crystal Springs Reservoir.
Water to be accounted for by draft upon the pipe line by slip at pumps and by unexplained losses.

nary 1902 - 1908 — Million Gallons per day

th	1903 Rain Inches	1903 To be Acc.for	1903 Rain Inches	1903 To be Acc.for	1904 Rain Inches	1904 To be Acc.for	1905 Rain Inches	1905 To be Acc.for
	1.19	2.22	0	1.78	.41	----	3.15	----
e	0.12	4.17	0	.93		1.18	0	----
y	0	3.40	0	3.17	.02	1.96	0	2.03
	0	4.26	0	2.87	.04	2.59	0	1.83
t	0	2.39	0	1.63	5.14	----	0	.92
	2.77	2.42	2.77	2.76	4.21	----	0	1.19
	4.29	4.08	9.23	----	1.50	----	2.51	.81

th	1906 Rain Inches	1906 To be Acc. for	1907 Rain Inches	1907 To be Acct. for	1908 Rain Inches	1908 To be Acc. for
	3.01	----	.35	----	1.16	3.41
e	.42	.22	.80	1.83		3.62
y	0	1.39	0	3.59	.10	3.30
0	0	8.89	0	3.86	.02	4.11
t	.13	7.05	0	3.63		8.01
	.01	2.84	1.95	3.28	1.13	0.74
	2.15	3.14	.03	4.15	2.11	----

By diagrams in Figs. 7, 8 and 9 an attempt has been made to show the relation of rainfall and the inflow of water into Crystal Springs reservoir. Here too no account has been taken of the draft by San Mateo and other water users outside of San Francisco and no correction has been applied for the slip in the pumps. The lines shown below the base lines of the diagrams would all be above the same if evaporation has not been underestimated, if there is no leakage from the reservoir and if a suitable correction is applied of about 0.46 to 0.75 million gallons per day for water used near San Mateo and for slip in the Belmont pumps.

The question arises whether the water not accounted for is lost from the entire reservoir or only from the upper, or from the lower portion thereof. Some information on this subject is obtained by examining the records which relate to the Upper Crystal Springs reservoir. This reservoir was used independently until 1889.

The years 1878 to 1887 were selected for examination and the result is presented in Tables XI and XII.

CRYSTAL SPRINGS RESERVOIR

1894-5, a selected year with heavy rainfall

Prepared for the City and County of San Francisco

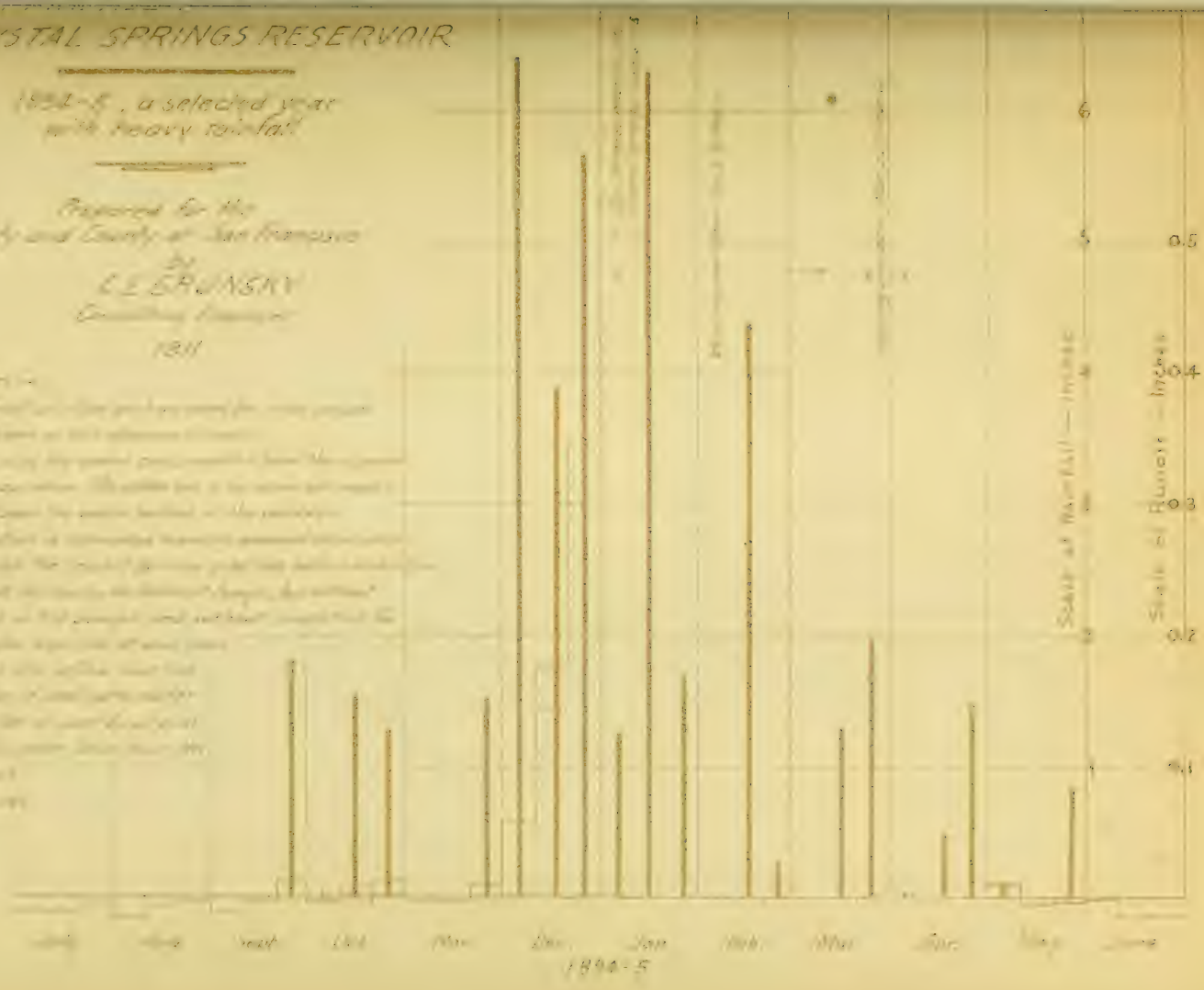
By

C. E. GRUNSKY

Consulting Engineer

1911

Explanation:—

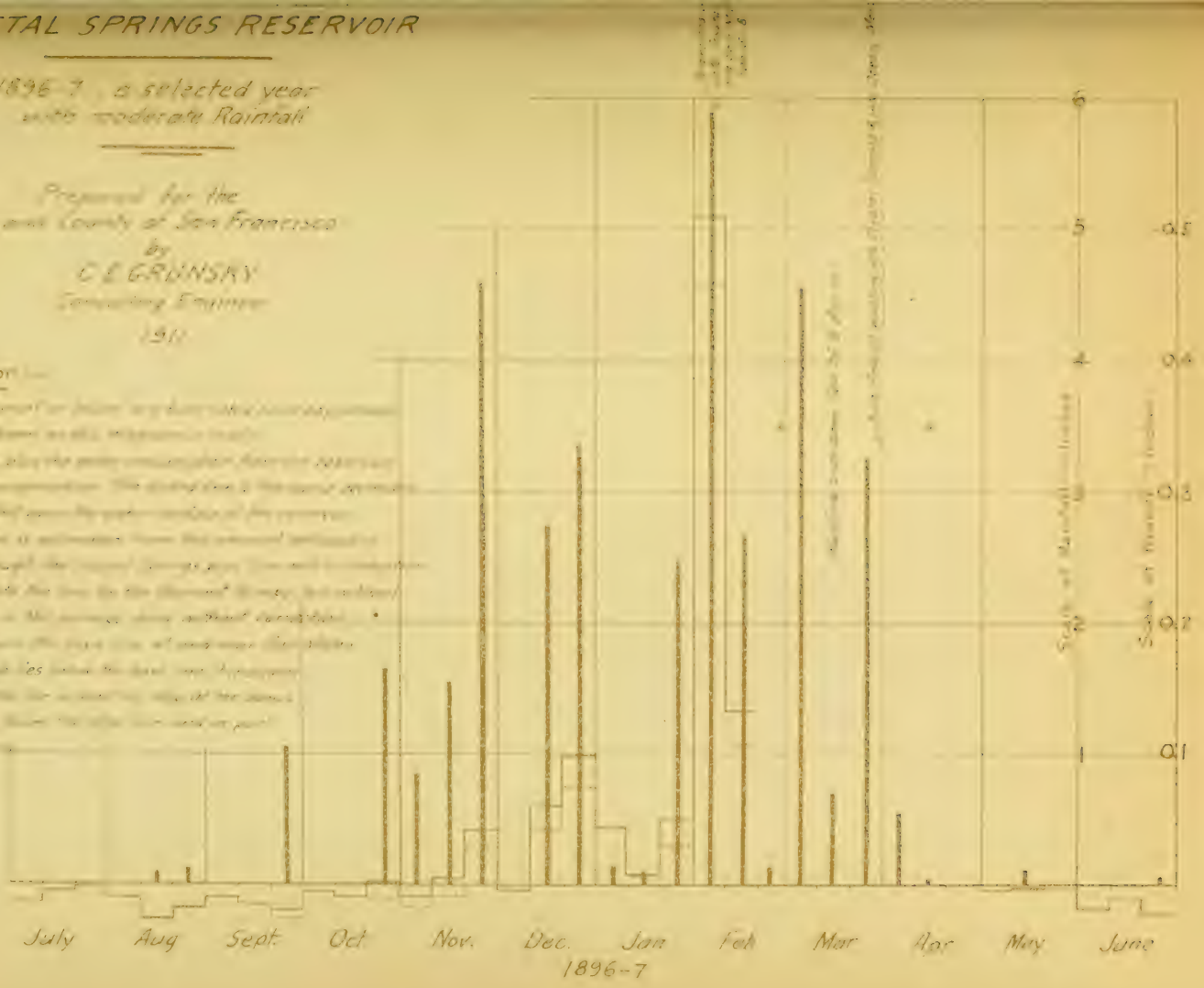


CRYSTAL SPRINGS RESERVOIR

1896-7, a selected year with moderate Rainfall

Prepared for the City and County of San Francisco by C. E. GRUNSKY Consulting Engineer 1911

Explanation



1897-8 ... a seasonal year with [illegible] months

Prepared for the
City and County of San Francisco
By
C. B. Goodrich
[illegible]
1901

Explanation

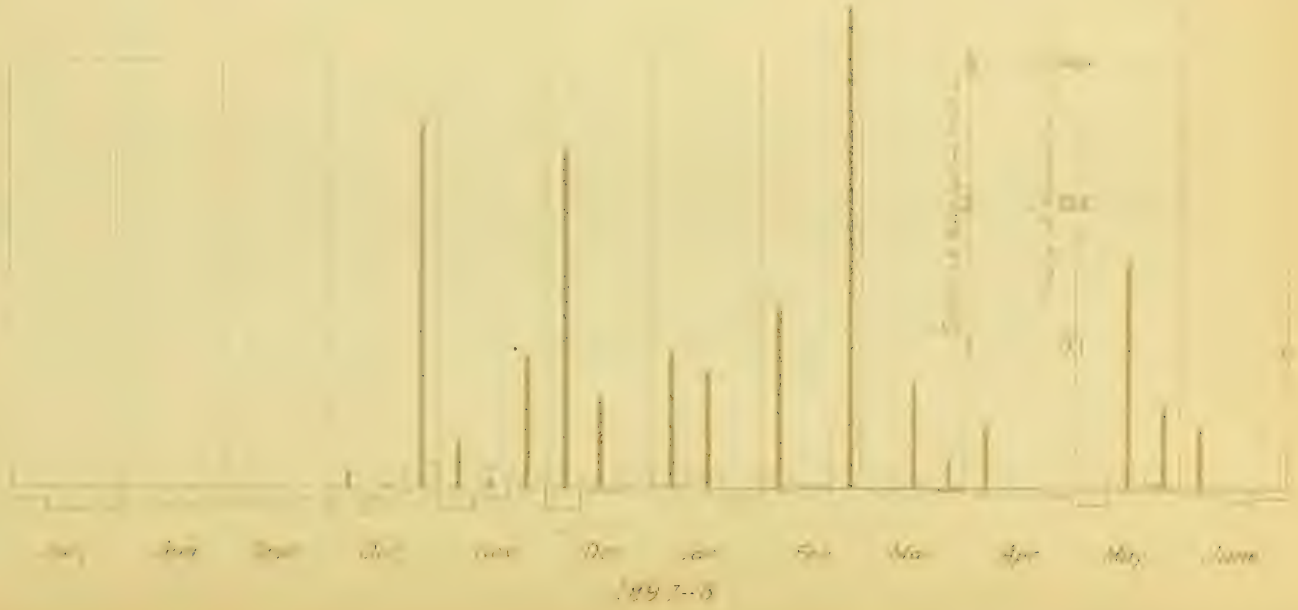


TABLE XI

Upper Crystal Springs.
Water Production 1878 to 1907.

Month	Rain Inches	Res Area Acres	Million Gallons per day: Draft D.	Evap. E.	G. or L. G.	Rain R.	X
1878							
June	0	450	0	1.56	-2.30	0	- .75
July	0	445	0	1.74	-2.69	0	- .95
Aug	0	440	0	1.71	-2.82	0	-1.11
Sept	1.41	430	0	1.58	-1.70	.54	- .66
Oct	2.36	430	0	1.37	- .13	.89	.35
Nov	0.81	430	0	.87	-1.42	.31	- .76
1879							
June	0	440	0	1.74	-2.34	0	- .40
July	0	435	0	1.81	-2.89	0	-1.27
Aug	0	430	0	1.84	-2.75	0	- .91
Sept	0	435	0	1.41	-2.15	0	- .74
Oct	1.68	430	0	1.15	-1.07	.68	- .54
Nov	4.14	430	0	.60	.46	1.57	- .51
1880							
June	0	450	0	1.71	-1.80	0	- .19
July	0	445	0	1.47	-3.61	0	-3.14
Aug	0	440	0	1.51	-2.71	0	-1.20
Sept	0	435	0	1.55	-1.93	0	- .38
Oct	0	430	0	1.07	-1.37	0	- .30
Nov	0	430	0	.50	-1.04	0	- .54
1881							
June	.60	430	0	1.13	-2.03	.83	-1.13
July	.28	425	0	1.25	-2.80	.07	-1.64
Aug	0.	420	0	1.05	-2.88	0	-1.83
Sept	.71	415	0	.97	-3.13	.87	-2.43
Oct	1.11	410	0	.58	-1.31	.40	-1.13
Nov	2.00	405	0	.37	-1.45	.73	-1.81

\# Incomplete draft as explained in the text.
R is the rain which falls upon the water surface of the reservoir.
$X = D + E + G - R$
When there is a decrease of storage instead of gain G will be negative.

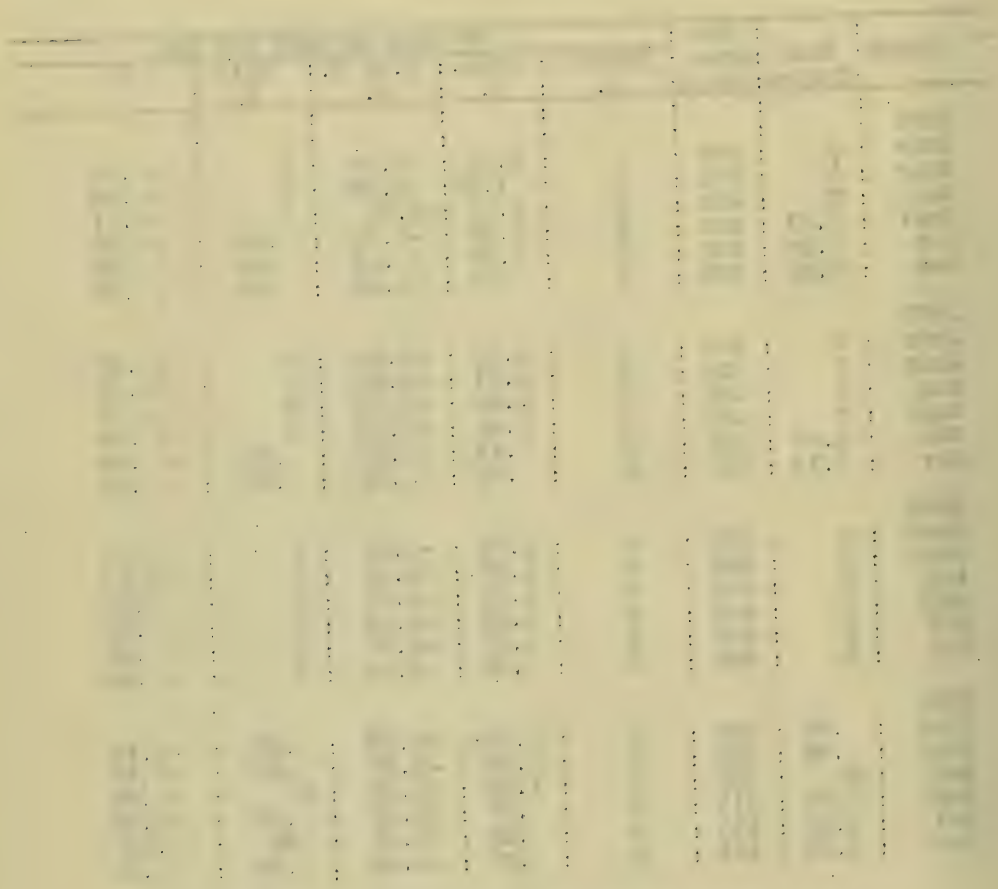


TABLE XI (Continued)

Upper Crystal Springs.
Water Production 1878 to 1887.

Month	Rain Inches	Res. Area Acres	Million Gallons per day: Draft D.	Evap. E.	G. or L. G.	Rain R.	X
1882							
June	0	430	0	1.00	-2.27	0	-1.27
July	0	425	0	1.03	-2.73	0	-1.70
Aug	0	420	0	1.30	-2.86	0	-1.56
Sept	.45	415	0	1.11	-2.00	.17	-1.06
Oct	2.34	415	0	.84	.18	.85	.17
Nov	5.24	415	0	.47	.88	1.97	- .62
1883							
June	0	405	2.42	1.38	-4.66	0	- .86
July	0	395	2.42	1.16	-4.87	0	-1.29
Aug	0	385	2.15	1.04	-4.48	0	-1.29
Sept	0	375	2.32	1.31	-3.41	0	- .82
Oct	2.32	365	1.41	.64	-2.03	.74	- .72
Nov	1.23	365	0	.42	- .16	.41	- .15
1884							
June	0	435	0	1.18	- .10	0	1.08
July	0	430	0	1.26	-3.68	0	-2.42
Aug	0	425	0	1.09	-2.20	0	-1.11
Sept	.44	425	0	1.07	-1.75	.17	- .85
Oct	3.27	420	0	.71	- .18	1.20	- .67
Nov	.40	430	0	.65	- .92	.15	- .42

TABLE XI Continued)

Upper Crystal Springs
Water Production - 1878 to 1887

Month	Rain Inches	Res. Area Acres	Million Gallons per day: Draft D.	Evap. E.	C. or L. G.	Rain R.	X
1885							
June	0	430	0	1.19	- 2.65	0	-1.46
July	0	435	0	1.82	- 3.41	0	-1.59
Aug	0	410	5.00	1.47	- 8.20	0	-1.64
Sept	.08	385	4.41	1.55	- 7.11	.03	-1.18
Oct	.14	375	6.49	1.12	- 9.25	.05	-1.69
Nov	11.75	360	6.63	.78	1.30	-3.85	4.86
1886							
June	0	425	8.13	1.68	-11.18	0	-1.37
July	0	400	7.25	1.75	- 6.88	0	2.12
Aug	0	380	7.38	1.56	- 9.60	0	- .76
Sept	0	355	8.08	1.27	-10.81	0	-1.56
Oct	1.70	335	6.70	.81	- 8.45	.50	-1.44
Nov	1.15	320	7.44	.53	- 7.29	.33	- .88
1887							
June	0	300	1.52	1.06	- 3.44	0	- .86
July	0	290	1.73	.84	- 3.92	0	-1.25
Aug	0	275	1.51	.88	- 3.50	0	-1.11
Sept	1.17	265	1.97	.90	- 3.08	.28	- .49
Oct	0	255	.58	.87	- 3.09	0	-1.70
Nov	2.43	250	1.34	.34	- 1.97	.55	- .84

TABLE XII.

Upper Crystal Springs Reservoir.
(Since 1889 this is a part of Crystal Springs Reservoir)
Water to be accounted for by slip in the pumps
and unexplained losses.

ummary - 1878 to 1887 — Million Gallons per day

onth	1878 Rain Inches	1878 To be Acc.for	1879 Rain Inches	1879 To Be Ac.for	1880 Rain Inches	1880 To be Ac.for	1881 Rain Inches	1881 To be Ac.for	1882 Rain Inches	1882 To be Ac.for
une	0	.75	0	.40	0	.18	.60	1.13	0	1.27
uly	0	.95	0	1.37	0	2.14	.25	1.64	0	1.70
ug	0	1.11	0	.81	0	1.20	0	1.83	0	1.56
ept	1.41	.66	0	.74	0	.38	.71	2.48	.45	1.06
ct	3.36	----	1.68	.54	0	.30	1.11	1.13	2.34	----
ov	.81	.76	4.14	.51	0	.54	2.00	1.81	5.24	0.62

onth	1883 Rain Inches	1883 To be Ac.for	1884 Rain Inches	1884 To be Ac.for	1885 Rain Inches	1885 To be Ac.for	1886 Rain Inches	1886 To be Ac.for	1887 Rain Inches	1887 To be Ac.for
une	0	.86	0	----	0	1.46	0	1.39	0	.86
uly	0	1.20	0	2.48	0	1.59	0	----	0	1.25
ug	0	1.39	0	1.11	0	1.64	0	.76	0	1.11
ept	0	----	.44	.85	.03	1.18	0	1.52	1.17	.49
ct	3.38	.72	3.27	.67	.14	1.60	1.70	1.41	0	1.70
ov	1.81	.15	.40	.42	11.75	----	1.15	----	7.43	.84

Three months- July 1880, September 1881, and July 1884- are noted in which in the case of the upper Crystal Springs reservoir the water not accounted for amounts to more than 2,000,000 gallons per day. In ten other months this loss was more than 1,500,000 gallons and practically all other summer and fall months in which there is not rain show some unexplained loss.

November 1881 with 2 inches of rain preceded by an October with 1.11 inches of rain shows 1,810,000 gallons of water per day unaccounted for; October 1885 shows

1,690,000 gallons per day, and October 1887 shows 1,700,000 gallons per day. There was a little rain in September 1885 and also some in October, and the water surface area exposed to evaporation was 375 acres. In 1887 there was no rain in October, but there has been 1,17 inches of rain in September.

These facts seem to indicate that a part of the unexplained loss of water is from Upper Crystal Springs reservoir, but that the major portion thereof is from the subsequently added lower part of the reservoir. This apportionment of the unexplained loss taken by itself would indicate that evaporation has been underestimated. But the loss is too large both for the upper reservoir by itself (being the water unaccounted for plus some unknown inflow) and for the entire reservoir, to allow the acceptance of under-estimated evaporation as a complete satisfactory explanation.

If there were no summer runoff from the watershed and if the unexplained loss, at a moderate stage of the reservoir, is a nearly uniform amount, as it might be in the case of leakage, then some uniformity in the figures presented in the tables might be expected. The lack of uniformity may be attributed to the variable inflow. The inflow in the summer comes mainly from the percolating waters,which, according to frequency,character and duration of rain storms of the preceding winters, may vary in quantity within wide limits.

On the assumption that the use of water from the pipe line and the slip in the pumps is an exact offset to the inflow in the months below named, the figures in Tables IX and X, taking into account such months as July and August 1894; June and July 1895; August, September and October 1896; June, July, August, September and October 1897; July, August, September, October and November 1898, June, July, August and November 1902; July 1903; August, September and November 1906; July, August, September and October and November 1907; and May, June, July, August and September 1908; indicate the amount of water unaccounted for at about 4.62 million gallons per day.

If only those months be considered in which the average amount noted in the table exceeds 5 million gallons per day, it will be seen that there were nine such months in the twelve years covered by the table, indicating 6.90 million gallons per day as the average amount, unaccounted for.

If the extreme assumption be made that there was no inflow whatever in any of the months which have been enumerated these amounts become about 3.9 million gallons per day and 6.2 million gallons, the reduction being the correction for water taken from the pipe and slip in the pumps.

It seems possible in the light of this analysis that there is a continuous deficiency in the water accounted for by the records of over six million gallons per day.

Some of this water may perhaps be accounted for by errors of measurement, though material errors of measurement do not seem probable. Some of it is perhaps an underestimate of evaporation, but as the total defection is large, and as no such underestimate is indicated by the application of the same rates to Pilarcitos and San Andres reservoirs, it does not seem probable that much of the loss from the reservoir which the figures indicate can thus be accounted for,

The most, if not all, may be leakage. Leakage must be admitted to be possible, particularly as the rift in the earth's crust on which there was movement during the earthquake of 1906 passes longitudinally through the reservoir.

Leakage, if it exists, is a continuous loss which may vary in some degree with the stage of water in the reservoir, but it is probably very nearly uniform for ordinary stages. The figures in the tables when compared with the elevation of the water surface in the reservoir give no clue to any variation dependent upon water stage.

If evaporation must account for the unexplained loss, then this loss should be greatest at highest stages of the reservoirs when the area of the water surface is greatest and during the hottest months of the year. Such amounts of water unaccounted for, as over

5 million gallons per day in nine summer months of the periods examined, and such amounts as 3,45 million gallons per day in October and 3.93 million gallons in November 1897, and 4.99 in October and 6.48 in November 1898, and 3.43 in October and 4.08 in November 1902, and 3.84 million gallons per day in October and 4.15 in November 1907, plus some probable excess of the unknown inflow over draft from the pipe line and slip of pumps, would seem to require some other explanation.

Nevertheless, if it can be shown that the water which is unaccounted for is an evaporation loss, then a very much smaller loss must be assumed for the winter months than the loss for the warm dry portion of the year for which alone the available records can be used to disclose a deficiency requiring explanation.

A continuous loss of about five million gallons per day would be equivalent to a depth of five inches per annum on the watershed tributary to Crystal Springs reservoir. This water is a part of the runoff or inflow into the reservoir but is not, as has been explained, available for consumption.

It is a matter of some importance that this question of loss be further investigated, particularly to settle the question whether there is leakage worthy of note and whether the leakage increases materially with increasing elevation of the water surface.

EVAPORATION RECORDS AT LAGUNA SECA

As a check upon the rates of evaporation which were assumed in determining evaporation losses from Crystal Springs reservoir, reference may be made to evaporation observations which were made for the Bay Cities Water Company by Mr. E. Duryea, Jr. at Laguna Seca, in Santa Clara County, about 13 miles southeasterly from San Jose, in 1904 and 1905. These observations were made with two pans floating in water besides a number of pans on the land.

One of the floating pans was near the East, the other near the West end of Laguna Seca. Laguna Seca is a shallow body of water, consequently the surface temperature of its water will follow the atmospheric means more closely than would be the case in a large deep reservoir and the results of observations, particularly for the summer months, are probably higher than they would be from a large reservoir.

Mr. Duryea's records show for the East pan in 1904 an observed evaporation on 259 days of 3.07 feet and an estimated evaporation for the remaining 106 days of the year of 0.52 feet, or a total for the year of 3.59 feet.

The results of the West pan in 1904 were by observation covering 223 days 3.80 feet and by estimate for the remaining 142 days 0.49 feet, or a total for the year of 3.29 feet.

For the year 1905 on 172 days the observed depth of evaporation from the East pan was 2.88 feet and the estimated evaporation on the remaining 193 days was 1.58 feet, making 4.46 feet for the year.

For the year 1905 on 168 days the observed depth of evaporation from the West pan was 2.12 feet and the estimated evaporation on the remaining 197 days was 1.47 feet, making for the year 3.59 feet.

Giving all these observations equal weight, it will be found that they indicate an annual evaporation from Laguna Seca-

For 1904 of about	3.44 feet.
for 1905 of about	4.02 feet.
Average	3.73 feet.

According to the records, the evaporation from the two pans in 1904 is quite comparable and in some months one pan, in other months the other pan shows the higher rate. But in 1905 the East pan shows 100 per cent more loss than the West pan in June, 25 per cent. more in July, 50 per cent. more in August and 50 per cent. less in September, than the West pan and there is consequently a wide discrepancy between the annual totals- 4.46 for the East pan and 3.59 for the West pan- which remains unexplained.

The amounts of evaporation from Laguna Seca are probably somewhat in excess, as stated, of the evaporation which should be expected from a large

reservoir such as Crystal Springs reservoir and they were made in a locality which is probably somewhat warmer than Crystal Springs.

A direct comparison of temperature can not be made for lack of records. However, at Gilroy which has a climate similar to Laguna Seca, the temperature is several degrees higher than at San Mateo, during the summer months, a difference which if it prevails between San Mateo and Laguna Seca, would, according to the evaporation curve, readily account for 10 to 20 per cent more evaporation in the southerly portion of Santa Clara Valley than in the neighborhood of San Mateo.

The observations made by Mr. Duryea indicate somewhat higher evaporation rates southward from San Jose than have been introduced(in the foregoing discussion) into the calculations of losses from bodies of water lying northwesterly from San Jose, on the Peninsula between the ocean and the Bay.

But in view of the fact that differences in monthly mean temperatures are to be assumed and because the Duryea results should probably be somewhat reduced for application to large deep bodies of water, they may yet be considered, in some measure at least, as confirmatory of the evaporation rates introduced into the computation of the evaporation losses from the Crystal Springs reservoir. These losses for the year 1904 amount to 3.19 feet and for the year 1905 to 3.15 feet. These values are to be compared with the losses at Laguna Seca reported by

Mr. Duryea, of 3.44 feet and 4.02 feet respectively.

There is of course, too, some pppor-tunity for error in the Duryea results, first, because to some extent the evaporation was estimated (in 1905 about one-third of the annual in the case of the East pan, and about two-fifths in the case of the West pan) and second, because some errors are probable in the scale readings which were the basis of the records. It is understood that the readings to determine loss were all made at the water-surface on a vertical scale. No particular refinement was deemed necessary because the purpose of the observations was merely to establish a safe annual rate of evaporation to be assumed in discussing reservoir efficiency in that part of the State.

During the same two years covered by the observations at Laguna Seca there were also made by Mr. Duryea observations of evaporation from a pan floating in the water of Coyote Creek, some miles above the point where the Creek breaks through the upper gorge into the valley northeasterly from Morgan Hill.

The evaporation observed on 260 days in 1904 was 2.32 feet and the estimated evaporation for the remaining 105 days was 0.54 feet, making the total for the year about 2.86 feet.

The evaporation observed on 217 days in 1905 was 1.79 feet and the estimated evaporation for the remaining 148 days was 0.73 feet, making the total for the year about 2.52 feet.

These amounts from the surface of Coyote Creek are probably somewhat less than should be expected from a large open water surface, which would be less protected against wind and sun by banks, trees and mountains than a pan floating in a pool in the channel of the creek.

CHAPTER III

RAINFALL, RUNOFF AND WATER UTILIZATION From Areas near San Francisco.

RAINFALL, RUNOFF AND WATER UTILIZATION

From Areas near San Francisco.

By C. E. Grunsky, Consulting Engineer.

1911.

The relation to runoff to rain in Coast Range regions near San Francisco was quite fully discussed by the writer in a paper read before the American Society of Civil Engineers in 1908. (See Rain and Runoff near San Francisco, Transactions American Society of Civil Engineers, Vol. LXI)

The fact that there was a greater loss of water from Crystal Springs Reservoir than due to ordinary rates of evaporation was not discovered when that paper was prepared, because at that time annual totals alone entered into the calculation and the negative values for runoff at this reservoir during practically all summer months when there was no rain and also during some winter months did not then become apparent.

It is now clear that the inflow into Crystal Springs Reservoir was under-estimated and that the deficiency probably amounts to more than 5 million gallons per day, of which about 4.6 million gallons is the apparent amount shown to be unaccounted for in 35 months of the 12 years which have been selected for study.

Perhaps the water that is not accounted for, if it could be accurately determined, could

be shown to materially exceed 5 million gallons per day in some or all summer months, and perhaps it would fall under this amount in winter, depending upon whether evaporation is an important source of error or not. At any rate as early in the year as May in four years out of the twelve which were examined, and as late as November in four years the amount is large. Notwithstanding rain in October and November of the latter four years, the water not accounted for in November when the evaporation rate is ordinarily only 2 to 3 million gallons per day from a full reservoir is shown by the figures in Tables IX and X to be at times from 4 to 6 million gallons per day.

In the runoff study of 1908, already referred to, evaporation by the year was introduced into the calculation at 48 inches. This was probably an overestimate to the extent of 25 per cent and this overestimate is a partial offset to the correction that is now to be made for the unexplained loss of water from the reservoir.

Expressed in inches of runoff the 5 million gallons per day, which for the present may be accepted as an unexplained loss of water from the reservoir, would amount to 4.8 inches on the 32.5 square miles of the watershed of Crystal Springs Reservoir in one year. The overestimate of evaporation in 1908 was probably equivalent to about 0.8 inches on the same watershed. Consequently the values noted in 1908 for depth

of runoff from the watershed of Crystal Springs Reservoir are throughout about (4.8 - 0.8 =) 4.0 inches less than they should be.

It is known too that some correction is also applicable to the records applying to Upper Crystal Springs Reservoir. This correction may, for the purposes of approximation, be taken at 2 million gallons per day or about 3 inches of runoff per year on the 13.8 square miles of tributary watershed. (See Table XII). The correction for over-estimate of evaporation in this case amounts to 0.5 inch, making 3.5 inches as the net correction to be applied to the runoff figures of 1908.

Owing to the fact that for some years after the construction of the Upper Crystal Springs Reservoir its water was not used, the runoff has been estimated only for the years beginning with 1881-82.

For the combined runoff of Pilarcitos and San Andres Reservoirs in the light of better information relating to evaporation the figures used as the basis of the paper of 1908 were also subjected to a small correction. Here too the evaporation was then introduced into the calculation at 48 inches per year, whereas it should have been taken at about 36 inches. This means that the runoff values expressed in depth on the watershed, as then used, are too large by about 0.8 inches.

With corrections as here indicated applied to the original figures of 1908 the data available

for a runoff curve applicable to land only- without inclusion of water surface- are as follows:

Year	Pilarcitos and San Andres: Pilar. and S. A. Reservoir: Rain Inches	Runoff frm land only Inches	Crystal Springs Reservoir: Rain Inches	Runoff from land only Inches	
1869-70	45.3	11.3			
70-71	36.8	5.7			
71-72	84.6				
72-73	41.1	18.2			
73-74	52.4	19.0 +			
74-75	46.6	11.3			
75-76	72.9	33.0 +			
76-77	33.5	1.2			
77-78	71.6	36.4 +			
78-79	51.9	20.0			
79-80	56.5	25.3			
80-81	51.2	21.0			
81-82	32.8	13.7	23.6	7.8+	Upper Crys. Spgs.
82-83	31.7	11.7	23.9	3.9	" " "
83-84	52.7	24.9	39.0	6.8+	" " "
84-85	38.8	13.0	33.5	4.3	" " "
85-86	51.8	8 .7	37.3	13.0	" " "
86-87	36.0	16.9	26.0	5.6	" " "
87-88	35.4	13.6	25.4	6.7	" " "
88-89	39.3	13.2	31.8	15.1	Crystal Springs
89-90	74.4	36.8+	60.1	48.4#	" "
90-91	37.6	9.4	30.3	13.5	" "
91-92	37.9	6.1	30.6	8.2	" "
92-93	54.2	17.3	43.7	21.8	" "
93-94	49.3	13.8	39.8	14.0	" "
94-95	64.5	18.0	52.1	23.0	" "
95-96	47.5	14.3	38.4	10.3	" "
96-97	46.2	30.3	38.0	13.2	" "
97-98	24.8	3.7	20.0	2.0	" "
98-99	40.5	8.1	33.7	9.1	" "
99-00	42.5	16.4	38.3	8.7	" "
1900-01	42.1	17.2	34.0	5.4	" "
01-02	38.9	18.0	31.5	6.1	" "
02-03	37.5	25.8	30.3	12.7	" "

This is undoubtedly an over estimate. It includes a large amount of waste as approximated by the Spring Valley Water Company.

These values have been platted, Fig. 10, and with due consideration of the well known general shape of a runoff curve have been made the basis of the curve there shown.

This curve is in much closer conformity with the curve adopted by the writer in 1908, for Sierra Nevada conditions than the earlier Coast Range curve and it is believed that until better data are secured it may be used generally for California conditions and will not be far in error if applied anywhere in the United States. It must be remembered, however, that it represents average conditions and that in single years there may be a wide departure from the probability indicated by the curve. The runoff may be less than one-half, or it may, particularly for moderate amounts of rain, be more than double the amount which would be predicted from the curve. But the curve is reliable as a means of approximating the mean runoff for long periods of time, and is therefore a valuable aid in determining the possible water productiveness of any region whose normal annual rainfall is known.

According to this runoff curve there are to be expected the amounts of runoff for various amounts of rain on the watershed as set forth in the following table:

RAINFALL AND RUNOFF
THE RUNOFF CURVE

Prepared for the
City and County of San Francisco
by
L. E. GRUNSKY
Consulting Engineer
1921

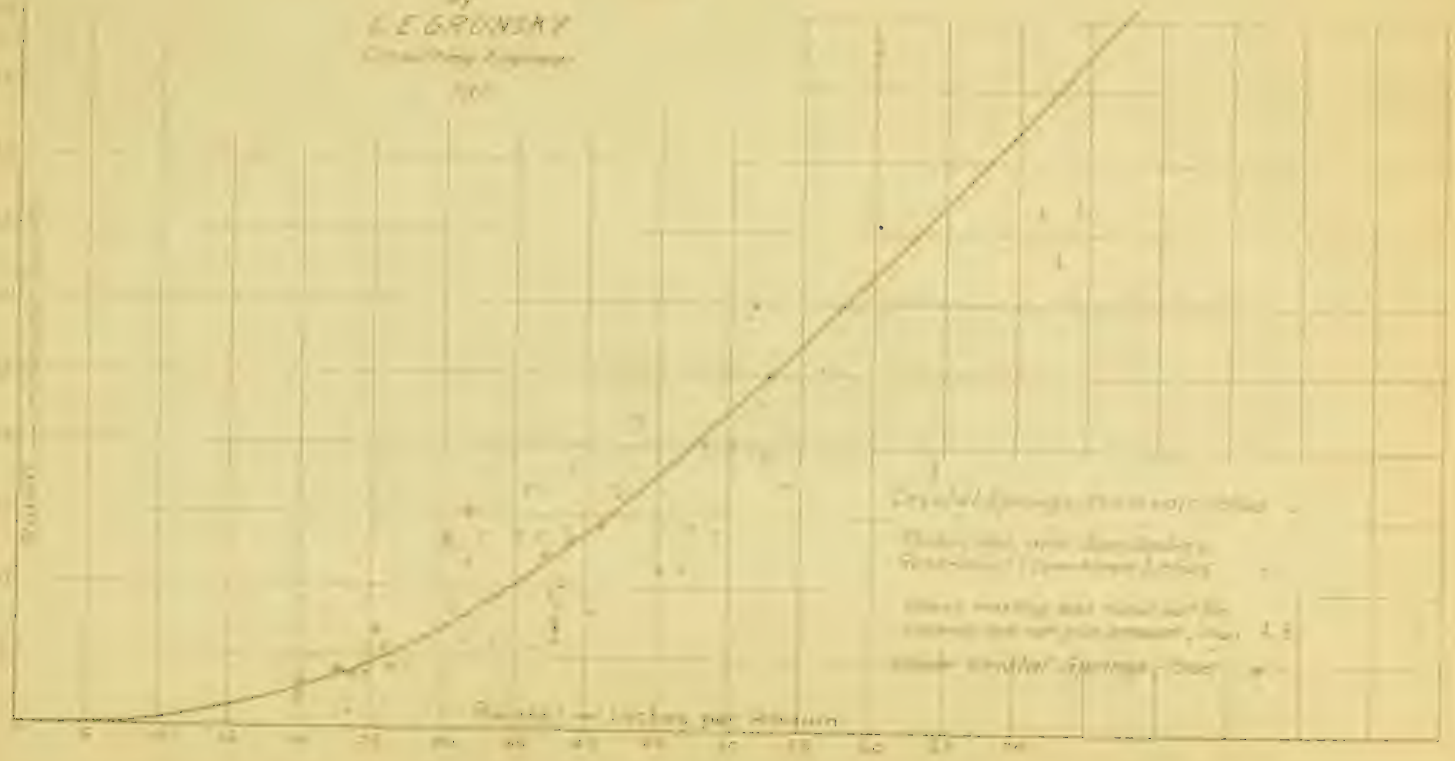


TABLE XIV

RELATION OF RAIN AND RUNOFF.

Rain - Annual Oct.1 to Oct.1 Inches	Runoff- Annual Oct 1 to Oct 1 Inches	Rain - Annual Oct 1 to Oct 1 Inches	Runoff-Annual Oct 1 to Oct 1 Inches
5	0.3	30	7.0
10	0.6	35	10.0
13	0.8	40	13.5
14	1.1	45	17.7
18	1.8	50	22.2
18	2.0	55	27.0
20	2.6	60	33.0
23	3.1	70	43.0
24	4.1	80	53.0
28	5.0		
33	6.0		

The annual rain varies in California within wide limits. It may be as low as 40 per cent of the normal or even somewhat less, and it may be twice the normal. In order to determine how many seasons should be assumed normal and how many above and below normal the following data relating to the area tributary to the south arm of San Francisco Bay have been compiled.

The rain year totals of rain(from October 1 to October 1) were compared with station normals for San Francisco, for the Spring Valley Water Company's reservoirs on the peninsula, for San Jose, for Mr. Hamilton, for Oakland, for Livermore and for San Mateo. For each of these stations in place of actual amounts of rain the percentage of the normal was noted and the results were combined as shown in Table XV.

The records of rainfall at San Francisco which were taken into account in preparing the percentage column for San Francisco as noted in the table were as follows:

From 1849 to 1865 the record of Thos. Tennent and of the War Department at the Presidio.

From 1865 to 1867 the record of Tennent, the record at the Presidio and the record of Mr. John Pettee.

From 1867 to 1871 the records of Tennent, Pettee, at the Presidio and of the Spring Valley Water Company.

From 1871 to 1884 the records of Tennent, Pettee, at the Presidio, Spring Valley Water Company, Southern Pacific Company, and the U.S.Signal Service (later the U.S.Weather Bureau)

From 1884 to 1892, the records of Tennent, Pettee, U.S.Weather Bureau, and the Spring Valley Water Company.

From 1892 to 1903 the records of Pettee, the U. S. Weather Bureau and the Spring Valley Water Company.

From 1903 to 1909 the records of the U. S. Weather Bureau.

The normal annual rain at San Francisco was taken at 23.10 inches and with this the composite record obtained as above stated was compared.

For the record at the Peninsula reservoirs a composite was obtained by averaging the rainfall at Pilarcitos with the rainfall at San Andres and at Crystal Springs:

TABLE XV

Rainfall at Selected Stations.
In Percentages of Normals from
Oct 1st to Oct 1st

Year	San Fransco	San Mateo	Peninsula Reserv.	San Jose	Mt. Hamilton	Liver-more	Oak-land	Average The Bay Watershed
849-50:	143							143
50-51:	38							38
51-52:	80							80
52-53:	146							146
53-54:	94							94
54-55:	87							87
55-56:	80							80
56-57:	74							74
57-58:	80							80
58-59:	84							84
59-60:	94							94
60-61:	78							78
61-62:	213							213
62-63:	81							81
63-64:	40							40
64-65:	71							71
65-66:	95							95
66-67:	148		146					148
67-68:	172		177					175
68-69:	98		105					99
69-70:	79		94					87
70-71:	97		76					87
71-72:	137		175			121		145
72-73:	80		85			68		78
73-74:	108		108			78		98
74-75:	80	57	96	55		74	87	75
75-76:	118	123	151	135		127	116	138
76-77:	43	35	48	33		38	49	41
77-78:	140	129	148	134		112	130	132
78-79:	101	86	107	114		64	95	94
79-80:	100	100	117	95		102	90	103
80-81:	132	97	106	87		103	128	107
81-82:	70	60	68	82	81	74	73	74
82-83:	84	73	66	73	116	88	69	81
83-84:	130	111	109	140	181	145	126	134
84-85:	78	81	76	78	140#	77	73	77
85-86:	138	102	107	143	98	102	130	117
86-87:	84	76	74	70	76	71	75	76
87-88:	71	74	73	94	94	84	69	78
88-89:	104	94	81	100	68	101	86	92
89-90:	206	192	154	210	141	182	184	181

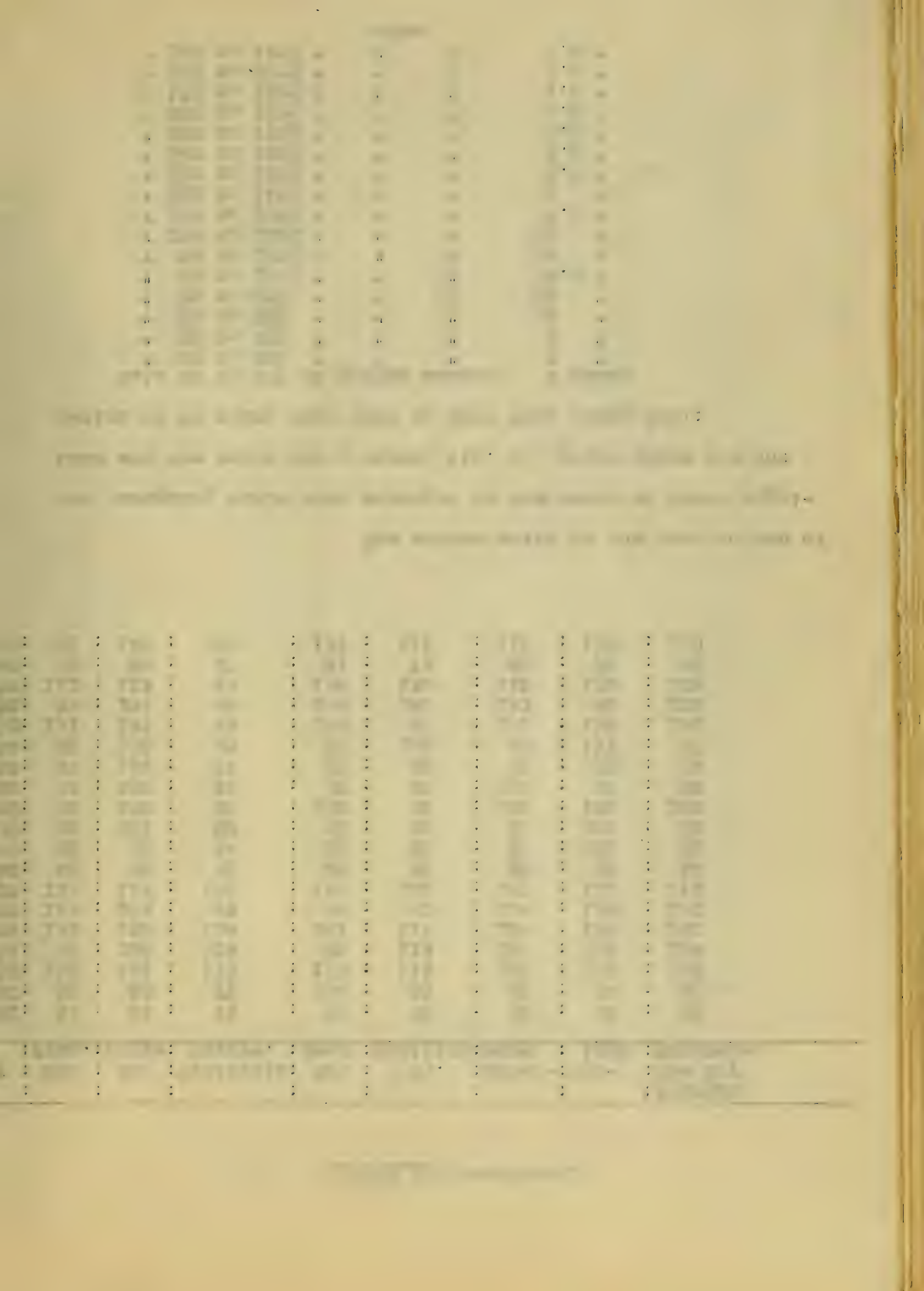
This undoubtedly an error. There is something wrong about the record 33.84 inches in Dec. 1884 when only 3.90 inches of rain fell at San Jose and only 7.68 in San Francisco.

TABLE XV (Continued)

Year	San Fran.	San Mateo	Peninsula Reserv.	San Jose	Mt. Hamilton	Liver-more	Oak-land	Average The Bay Watershed
890-91:	84	84	78	89	76	89	97	85
91-92:	86	83	79	114	86	91	84	89
92-93:	115	142	112	175	118	187	113	135
93-94:	98	106	102	89	112	109	103	105
94-95:	135	152	134	161	114	154	138	140
95-96:	114	105	98	95	93	104	108	103
96-97:	130	115	100	114	101	110	131	114
97-98:	48	56	51	48	55	58	55	53
98-99:	80	85	84	89	80	59	101	81
99-00:	98	101	88	96	92	81	100	81
00-01:	98	108	87	138	99	126	101	108
01-02:	73	100	81	90	87	107	97	93
02-03:	87	112	77	97	96	90	85	93
03-04:	89	108	98	73	106	85	117	97
04-05:	101	126	92	124	89	101	112	106
05-06:	89	108	86	105	120	123	96	103
06-07:	113	113	96	154	136	148	103	123
07-08:	75	63	57	81	75	63	64	68
08-09:	111	140	109	127	116	118	104	118

The values noted in the last column of the foregoing table when arranged in the order of their magnitude are the basis for a curve, Fig. 11, which shows for the period of 60 years from 1849 to 1909 that there fell:

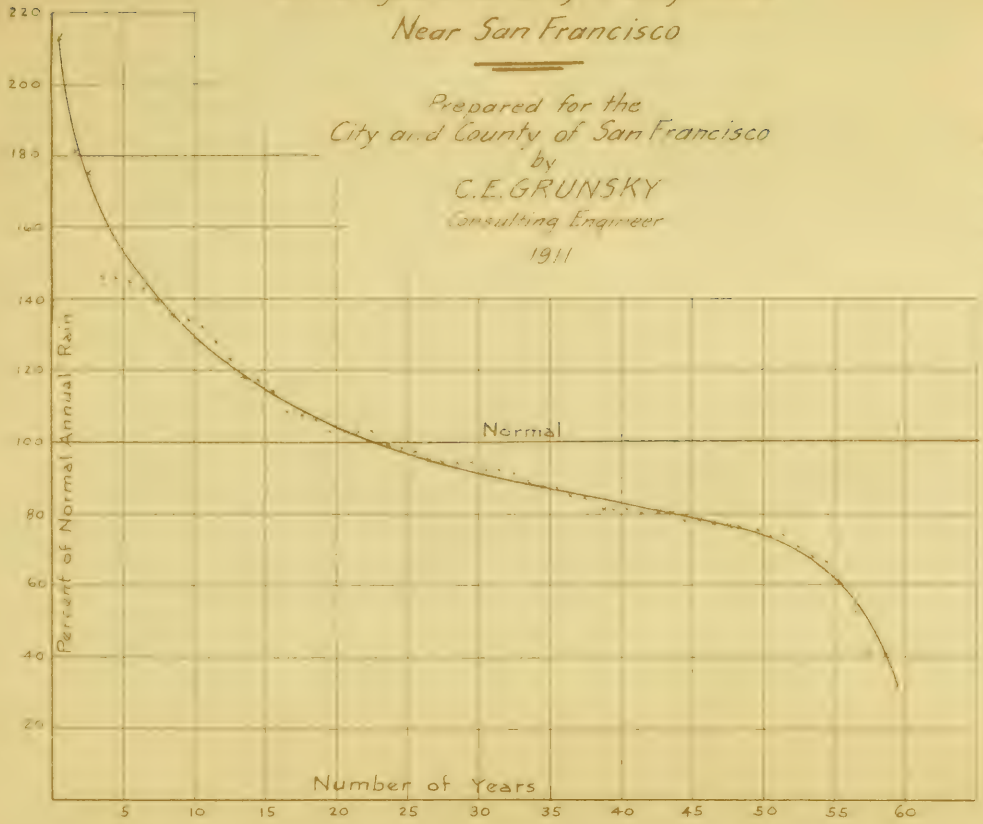
Rain	30 to 50%	of normal annual	3 years
"	40 to 60%	" " "	3 "
"	50 to 70%	" " "	4 "
"	60 to 80%	" " "	13 "
"	70 to 80%	" " "	21 "
"	80 to 100%	" " "	19.5 "
"	90 to 110%	" " "	15 "
"	100 to 120%	" " "	10 "
"	110 to 130%	" " "	7.5 "
"	120 to 140%	" " "	6 "
"	130 to 150%	" " "	4.5 "
"	140 to 160%	" " "	3.0 "
"	150 to 170%	" " "	2.5 "
"	160 to 180%	" " "	1.5 "
"	170 to 190%	" " "	1.5 "
"	180 to 200%	" " "	1.0 "
"	190 to 210%	" " "	1.0 "



RAINFALL
ANNUAL TOTALS

Arranged according to Magnitude
Near San Francisco

Prepared for the
City and County of San Francisco
by
C.E. GRUNSKY
Consulting Engineer
1911



Rainfall 1849 to 1909

Seasonal Totals expressed in percentage of normal

The Seasonal or Rain Year here used is from Oct. 1 to Oct. 1

The Curve here shown is made the basis of the curve Fig 2.

Based on records at

San Francisco	Mt. Hamilton
San Mateo	Livermore
Peninsula Reservoirs	Oakland
San Jose	

From the foregoing it appears that in the 60 years 1849 to 1909-

2.5%	of	the	years	averaged	about	40%	of	the	normal rain
2.5%	"	"	"	"	"	50%	"	"	"
3.3%	"	"	"	"	"	60%	"	"	"
10. %	"	"	"	"	"	70%	"	"	"
17.5%	"	"	"	"	"	80%	"	"	"
16.3%	"	"	"	"	"	90%	"	"	"
13.5%	"	"	"	"	"	100%	"	"	"
9.3%	"	"	"	"	"	110%	"	"	"
6.3%	"	"	"	"	"	120%	"	"	"
5.0%	"	"	"	"	"	130%	"	"	"
3.8%	"	"	"	"	"	140%	"	"	"
2.5%	"	"	"	"	"	150%	"	"	"
2.1%	"	"	"	"	"	160%	"	"	"
1.3%	"	"	"	"	"	170%	"	"	"
1.2%	"	"	"	"	"	180%	"	"	"
0.9%	"	"	"	"	"	190%	"	"	"
0.8%	"	"	"	"	"	200%	"	"	"

These values have been platted and a smoothed out curve substituted therefor as shown in Fig. 12.

It appears from this curve that in any long series of years there will be in the region under consideration:

1%	of the years with annual rain	to 40% of normal.
3%	" " " " " "	to 50% " "
5%	" " " " " "	to 60% " "
10%	" " " " " "	to 70% " "
17.5%	" " " " " "	to 80% " "
16.5%	" " " " " "	to 90% " "
12.5%	" " " " " "	to 100% " "
9%	" " " " " "	to 110% " "
7%	" " " " " "	to 120% " "
5%	" " " " " "	to 130% " "
3.5%	" " " " " "	to 140% " "
2.5%	" " " " " "	to 150% " "
2%	" " " " " "	to 160% " "
1.5%	" " " " " "	to 170% " "
1.3%	" " " " " "	to 180% " "
1.2%	" " " " " "	to 190% " "
1. %	" " " " " "	to 200% " "

RAINFALL

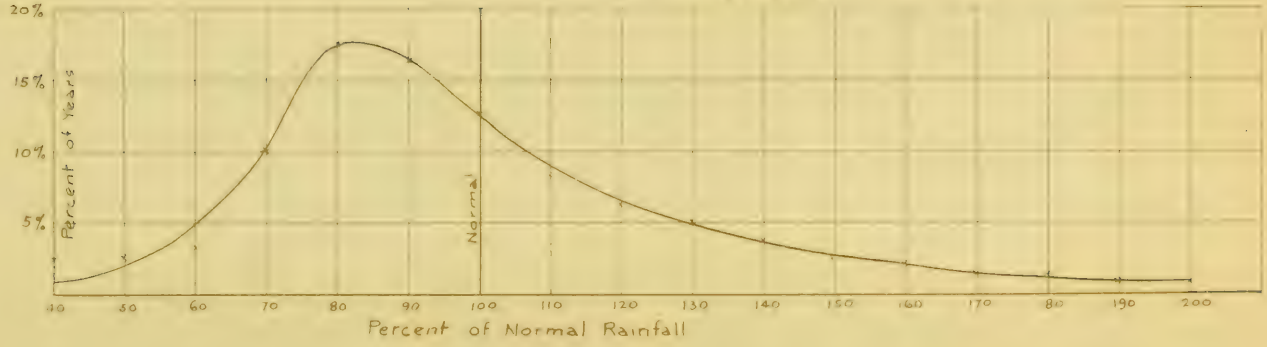
THE FREQUENCY OF ALL POSSIBLE ANNUAL AMOUNTS OF RAIN

Prepared for the
City and County of San Francisco
by
C. E. GRUNSKY
Consulting Engineer
1911

Explanation

The Curve gives the number of years in any long time period, expressed in percentage, in which the rain will be the amount indicated by the abscissae of the diagram.

Points on the curve apply to 10% increments of rain. Thus 10% of the years will have rain from 65 to 75% of normal



With the foregoing information relating to the frequency of normal, of wet and of dry years and a knowledge of the runoff which is probable for any amount of rain, it is possible to predict normal runoff when normal rain is known.

The figures will be noted in detail for a single example.

For a normal annual rain of 30 inches there will be:

1%	of the years with 12 inches of rain and	0.8 inches runoff
2%	15	1.3
5%	18	3.0
10%	21	2.45
17.5%	24	4.1
15.5%	27	5.5
12.5%	30	7.0
9 %	33	8.8
7 %	36	10.7
5 %	39	13.8
3.5%	42	16.2
3.5%	45	17.7
2 %	48	20.4
1.5%	51	23.2
1.3%	54	26.0
1.2%	57	29.0
1 %	60	32.0

Computed from these figures the normal annual runoff for a long series of years from a watershed whose normal rain is 30 inches is found to be 7.79 inches. This is 11 per cent more than the amount which is indicated by the ordinary runoff curve for a single year with rain equal to the normal annual rain.

In a similar way it is found that the normal runoff exceeds the corresponding single year runoff:

When the normal rain is 10 inches by 14 per cent

" " " " " 15 " " 14 " "

" " " " " 20 " " 14 " "

" " " " " 30 " " 11 " "

" " " " " 40 " " 8 " "

" " " " " 50 " " 4 " "

By substituting gallons per day per square mile for inches in depth per year, and platting the runoff as ordinates for rainfall as abscissae the lower curve in Fig. 13 is obtained and from this and the percentage correction above noted a normal runoff curve as shown by upper line in Fig. 13 has been constructed.

The values indicated by these curves are noted in the following table:

RELATION OF RUNOFF TO RAINFALL

Prepared for the
City and County of San Francisco
by
C. E. GRUNSKY
Consulting Engineer
1911

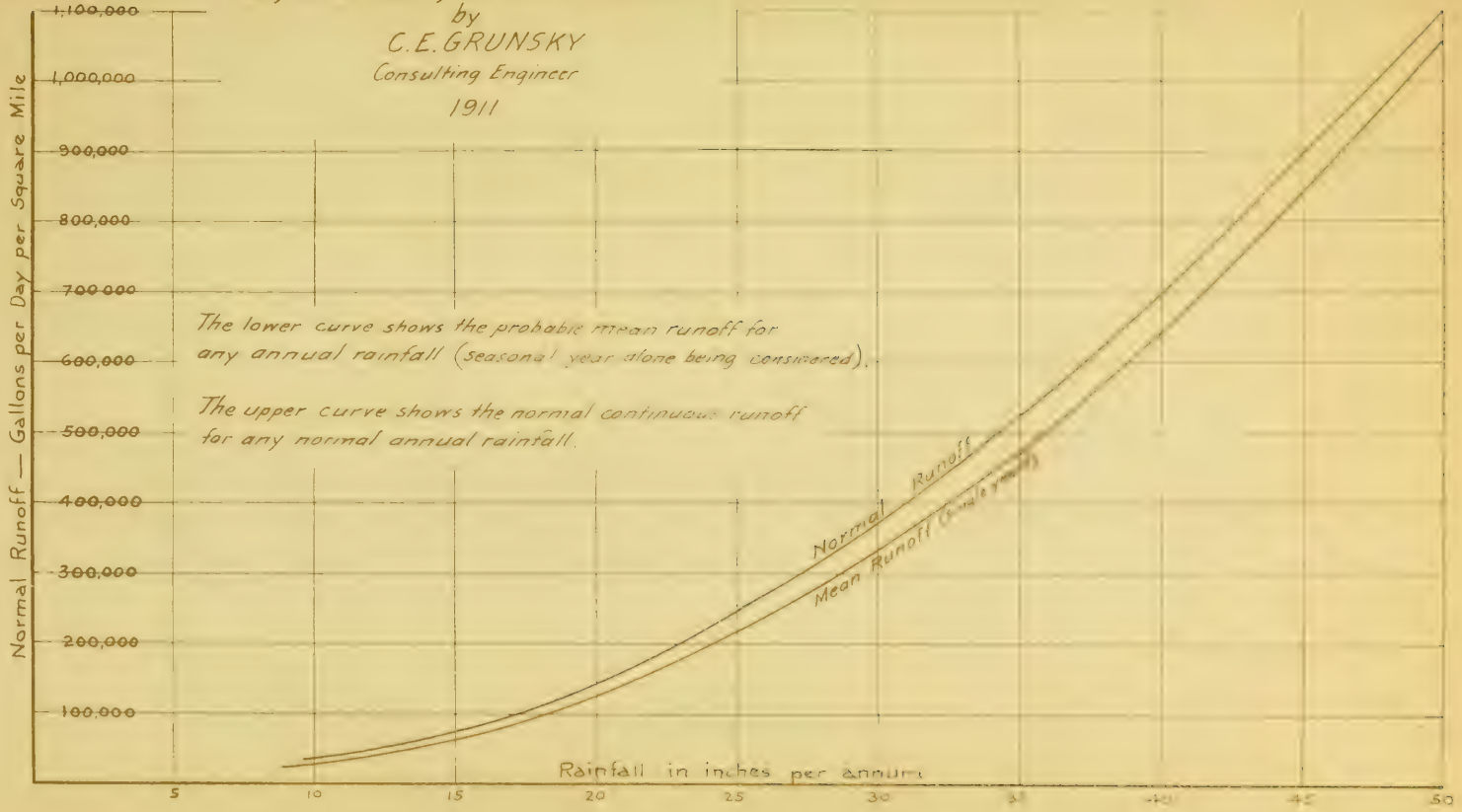


TABLE XVI

RELATION OF RAIN AND RUNOFF

For the rain year Oct. 1st to Oct. 1st.

Rain Annual or Normal Annual Inches	Probable Runoff during single years. Gallons per day per square mile.	Normal Runoff during a long series of years. Gallons per day per square mile.
10	38,000	32,000
15	63,000	71,000
20	124,000	142,000
25	214,000	241,000
30	333,000	370,000
35	476,000	523,000
40	644,000	695,000
45	845,000	896,000
50	1,055,000	1,098,000
55	1,285,000	
60	1,530,000	

The figures in table XVI were used in preparing the runoff map, Fig. 14, for the region near San Francisco which is offered as a fair exhibit of the water productiveness of the region tributary to the upper portion of San Francisco Bay and the peninsula streams which discharge into the ocean.

Runoff in the sense in which used in the foregoing discussion includes not only the water which under natural conditions actually flows or would flow in visible streams from the several watersheds into the Bay or the ocean, but also that part of the runoff which sinks into porous deposits, such as the gravels of Coyote Valley and of Santa Clara Valley in Santa Clara County, and the gravels of Livermore and Sunol Valleys, and the Niles cone in Alameda County.

The runoff as disclosed by the map for any region is not necessarily a measure of the amount of water that can be made available for utilization. Conditions are rarely so favorable that all of the runoff can be put to beneficial use. In order to accomplish this, large storage capacity is required to equalize the irregular stream flow. The area under consideration is almost devoid of visible runoff in the summer and fall. The streams are high only during the wet season, generally not before November nor after April and even during these months they flash up rapidly under the influence of a rainstorm and drop again quickly to a moderate flow after the storm is over. That this must be so is easily recognized when it is remembered that there are on an average only 70 rainy days in the year and nearly all of these fall into the wet period.

But even if adequate storage facilities could be provided on every stream in any of the large drainage basins of the region under consideration,

the utilization would still fall short of the runoff because the loss of water in such a case from the surface of the reservoirs would be considerable.

In the case of the Crystal Springs reservoir of the Spring Valley Water Company with a mean annual consumption for a long series of years of about 3,300 Million gallons per year, with relatively little waste, the loss by evaporation has been approximately 20 per cent of the runoff. The actual utilization in the case of this reservoir when compared with the runoff probably falls under 60 per cent.

From the map the normal runoff from the 23,5 square miles tributary to Crystal Springs reservoir, are estimated at 5,070 million gallons per year.

The evaporation is approximately 3 feet per year from a water surface of about 1000 acres or 987 million gallons per year.

In the case of the Pilarcitos and San Andres reservoirs (treated as a unit) it is estimated from the map that the normal runoff from the tributary areas is 5360 million gallons per year.

The utilization from these reservoirs has been approximately 3300 million gallons per year. The loss of water by evaporation has probably been about 440 million gallons per year.

For the two reservoirs, the Pilarcitos and San Andres, therefore, an efficiency of about 83 per cent may be noted and the evaporation loss alone is about 9 per cent of the total runoff. It is quite probable that under an extreme demand for water and a manipulation such that waste will be reduced to a minimum, the efficiency can be raised somewhat. In fact the consumption of water from the reservoirs during the past decade indicates a mean annual productiveness of about 4,000 million gallons which is to be compared with a mean annual runoff for this period of about 5,300 million gallons. This represents an efficiency of about 75 per cent.

These facts are here noted not so much for the purpose of indicating the water yield of the peninsula reservoirs, as of showing that even in the case of recognized favorable topographic conditions there can not be full utilization of the runoff from any watershed of considerable extent.

As a further illustration. The region directly and indirectly tributary to the proposed Calaveras reservoir in Alameda County, which has an area of about 135 square miles, has a normal runoff of about 46,400,000 gallons per day. The reservoir will have a mean surface area probably somewhere near 1500 acres, and the evaporation may be assumed at about 3.5 feet per year, in the aggregate 5,250 acre feet or about 4,650,000 gallons per day. This is 10 per cent of the estimated runoff. But there will be other reasons why full utilization can not be hoped for. A part

of the watershed is only indirectly tributary to Calaveras Valley. The water of Alameda Creek(formerly known as Hondo Creek) must be intercepted by a canal. There will be periods when the flow of the creek will exceed any reasonable canal capacity and this excess together with any surplus in Calaveras Creek itself, occuring as the result of heavy rainfall, will ordinarily be precipitated into the Sunol Valley and out over the Niles Cone at a time when local streams have already filled the gravels and will, therefore, in large part become unavailable for utilization. It could probably be shown for Calaveras Valley by an analysis of the runoff of past years about what percentage of the runoff from tributary areas will go past the reservoir, but this analysis has not been attempted. It is merely desired to make it clear that the conditions throughout the region under consideration are nowhere such that a full utilization of the runoff can be expected.

In this connection attention may be called to the fact that if works are planned to fully utilize by aid of storage all the runoff waters of every year with normal runoff and no more, or all the runoff waters of every year with less than one and one-half times the normal runoff, or finally all of the runoff waters of every year with less than twice the normal runoff and no more, there would still be an excess of runoff waters to be wasted in years of greater rainfall amounting in the first case to about 30%, in the second to about 17% and in the third to about 10% of the normal runoff.

Consequently even in the extreme case in which it might be possible to project works for an interception of twice the normal annual runoff, there would still be a waste without regard to evaporation of about 10 per cent.

But it is a well known fact that topographic and other conditions are rarely so favorable that a provision can be made to intercept for use more than from one to one and one-half times the normal flow and that, therefore, from 17 to 30 per cent of the runoff from this cause alone may be considered unavailable.

To the necessary waste resulting from the occasional excess flow, as pointed out, there is to be added the evaporation loss.

When, however, under the favorable topographic conditions which prevail at the Crystal Springs Reservoir, the efficiency factor is only 60 per cent and at the Pilarcitos and San Andres reservoirs the efficiency factor is only 75 per cent, it can not be hoped that a higher efficiency than about 66 per cent can ever be obtained for any large part of the region under discussion. Even this percentage, somewhat arbitrarily assumed, may on the basis of any carefully worked out comprehensive project be found to be too high. It has nevertheless been adopted for this discussion with a view to setting an upper limit to the forecast of ultimate water production in the bay region.

While in the foregoing discussion surface flow and water storage above the surface of the ground have alone been taken into account, some modification of the results should be made for those cases in which the result may be affected to some extent by subsurface storage, as in the case of the gravels of Coyote Valley, the gravels of Sunol Valley, and the artesian gravels of Livermore Valley.

All of such gravel deposits may be regarded as subsurface storage reservoirs, which can to some degree be made effective by draining them of their water as far as may be practicable, between the replenishing periods. Their productiveness is limited - 1st, by the rate of subsurface flow toward the point at which the water is withdrawn from them- 2nd, by their extent- 3rd, by the extent and character of the porous surface through which the stream or rainwater which feeds them sinks, and 4th, by the volume of water and the duration of its presence in the channel or on the surface at the points where it may sink into the subsurface strata. Neither the gravels in the Pleasanton Valley nor those of the Coyote Valley, nor the Niles Cone, nor the artesian belt of the Santa Clara Valley can take all the freshet flow which the tributary streams at times bring down from above. When the flow of the streams is regulated with more or less adequate reservoirs and when their freshet flow shall have been reduced to a minimum by water storage in the reservoirs, the amount of water entering the subsurface porous deposits may be materially decreased. On the other hand, by

exhausting the subsurface reservoirs of their stored supply and by increasing the area of inflow as by the construction of channels in the high lying portions of the gravel deposits, their output may be increased.

It is therefore apparent that the ordinary development of water by surface storage in the area tributary to the subsurface sources and draft upon the reservoirs through other conduits than the natural channels, will in some measure reduce the possible yield of these subsurface sources by decreasing the natural stream flow and that this effect of storage may in part be offset by improving the inflow conditions.

It is impossible on the basis of data now available to predict the extent to which the known subsurface gravel deposits will modify the efficiency factor of any of the streams under consideration. It can not be hoped that all freshet flow in excess of surface storage capacity will go into the gravel beds. A large portion thereof will, as in the past, rush over the surface. But as the gravels do take some water, and to a moderate extent act as equalizers of flow, it will be proper for this analysis to assign to them an arbitrary definite effect in reducing the waste of the stream flow.

It can be stated at the outset that their maximum feneficial effect can never quite bring the utilization efficiency of the entire tributary area up to 100 per cent. This may be approached when all runoff water

sinks into the ground but not otherwise. Assuming that in the tributary area, works are possible which will bring the efficiency to two-thirds and that the loss is distributed about 10% to evaporation from reservoirs and about 23% during freshets to waste, there will then be 33 % of the normal runoff available for storage in the gravel beds. Perhaps half of this can be made available under such conditions of periodical freshets as prevail in California, and under the imperfectly known conditions of inflow into the large gravel beds of the Santa Clara, Coyote, Livermore and Sunol Valleys, and the Niles Cone. This is, as stated, only an assumption predicated upon almost ideal conditions of water development on the streams above the gravel beds and should be considered as illustrative of the general principle rather than as a guide in determining what the gravels, taken by themselves, apart from the whole watersheds in which they lie, could be made to produce.

It may be repeated that the more nearly perfect the system is under which a utilization of water above the gravels is effected, the less water will be available to sink into and replenish any draft upon the gravels; and that the lower the efficiency of the water development works above the gravels the greater will be the amount of water that will be available for the replenishment and therefore the greater the water output of the gravels which can be made possible by suitable works such as galleries, wells and pumps. No system of conveying impounded waters into the localities where they will sink into and replenish the water in the gravel beds can add, as has already been stated, to the total water production of the regions except possibly by a small reduction of evaporation loss. The possibility is recognized and admitted, however, that more water can be forced into the gravels than would go there from the unregulated stream, and such water can be recovered in whole or in part.

For the purpose, therefore, of approximating the maximum possible water production of the entire Alameda Creek system, adequate storage above ground being assumed, and evaporation loss from open water bodies being introduced at 10 per cent, the probable efficiency may be placed at 67 plus one-half of 23 per cent, or about 80 per cent of the runoff.

But it is well known that, in the watersheds of such tributaries in this drainage system as the Alamo Creek, Tassajaro Creek, Las Positas Creek and generally in the lower portions of the drainage basin above the Pleasanton Gorge, there can be no material equalization of stream flow except by sub-surface storage. For these areas an assumption that 50 per cent of the runoff can be utilized is believed to be an over-estimate. These areas however have only a light rainfall and a small annual runoff and have not for the present been treated separately. The assumed efficiency of 80 per cent is applied to the whole watershed for the purpose of defining the upper limit of water development possibilities.

On the streams tributary to Santa Clara Valley the conditions are similar to those on Alameda Creek. The gravels of large extent in Coyote Valley are comparable with those in Livermore and Sunol Valleys. The artesian gravels which lie under the surface formations of the Santa Clara Valley extending northerly to the bay are

comparable with the Niles Cone. The combined drainage basin of Coyote Creek and Guadaloupe River at the Bay of San Francisco is about 657 square miles and that of Alameda Creek about 733 square miles.

For estimate purposes and again only with a view of reaching some idea of an upper limit for the possible ultimate water utilization from the streams flowing into the Santa Clara Valley there may here also an efficiency factor of 80 per cent be applied to the normal runoff.

In Table XVII estimates are presented of total runoff from the areas tributary to the South arm of San Francisco Bay.

TABLE XVII

RUNOFF FROM COAST RANGE AREAS
Watershed tributary to the South Arm of San Francisco Bay, Pescadero and other Ocean Slope Creeks.

Designation	Area Sq.Miles	Runoff, Gallons per day Sub-areas	Totals
Alameda Creek:			
Arroyo Valle at Proposed Rev.	138	29,500,000	
Other areas above Pleasanton Gorge,	260	25,100,000	
At Pleasanton Gorge,	398	54,600,000	
Calaveras Reservoir(proposed)			
Calaveras Creek,	100	35,100,000	
Alameda(formerly Hondo)Creek	35	11,300,000	
San Antonio Reservoir(proposed)	39	7,400,000	
Other areas Pleasanton to Sunol Dam	48	7,400,000	
At Sunol Dam,	630		115,800,000
Below Sunol Dam to the Bay	113	11,500,000	11,500,000
Coyote Creek:			
At Lower Gorge	242	117,700,000	
From Lower Gorge to S.F.Bay,	154	20,700,000	138,400,000
At San Francisco Bay,	396		

TABLE XVII (Continued)

Designation	Area Sq.Mi.	Runoff-Gallons per day: Sub-areas	Totals
Guadaloupe River:			
At San Francisco Bay	361		74,200,000
Portola Reservoir:	15		7,300,000
Peninsula Reservoirs:			
Pilarcitos and San Andres			
Pilarcitos	3.9	3,800,000	
San Andres	4.1	3,300,000	
Locks,Cr.Aq.etc.	4.8	5,300,000	
	12.8	14,400,000	
Crystal Springs	22.5	13,900,000	
	35.3		28,300,000
Other Creeks and Valley lands at San Francisco Bay	183		36,600,000
Ocean Slope Creeks:			
Pescadero-Below Peters Creek	295	37,700,000	
San Gregorio-Below junct. of Alpine and La Honda Creeks.	21.1	15,900,000	
Harrison Creek (At Elev. 385)	4.0	2,400,000	
Bogess Creek (At Elev. 380)	2.4	1,200,000	
Corte Madera (At Elev. 395)	7.7	4,000,000	
	84.9		81,200,000

The following example will illustrate how the figures in the foregoing table were obtained.

Alameda Creek at Sunol Dam has a drainage area of 620 square miles. This area may be subdivided according to rainfall as shown in the following Table.

TABLE XVIII
Runoff
Alameda Creek at Sunol Dam.

Rain	Area Sq.Miles	Normal Runoff-Gallons per day per sq.mile	Normal Runoff-Gallons per day
Less than 15 inches	52	60,000	3,100,000
15 to 20 inches	246	100,000	24,600,000
20 to 25 inches	144	190,000	27,400,000
25 to 30 inches	108	300,000	32,400,000
Over 30 inches	70	400,000	28,000,000
	620		115,500,000

All of the other computations were made in a similar way.

The runoff noted in Table XVII includes not only the visible flow of the streams but also the water which is moving in subsurface porous beds, such as the gravel cone which has its apex at Niles.

It remains to be stated that the efficiency factors which have been suggested for estimating the total available water supply from the runoff are subject to any change which experts may think desirable, particularly in those cases in which the utilization project is already well defined. The present purpose of applying efficiency factors to large areas, as has been stated, is to approximate the limit for the aggregate water yield re-

gardless of the purpose for which the water is used. There is but little doubt that if the analysis were made in detail for the area above each available storage basin with due regard to the fact that a large part of the watershed of the bay lies below the region of storage, the efficiency factor would be lower than has been assumed.

The water yield of the region under discussion is not all available for San Francisco. All of the population in the water sheds of Alameda Creek, of the Coyote Creek, of Guadaloupe River, and of the smaller creeks tributary to the bay whether water is obtained from surface sources or from wells, will draw upon this water for every need until water is brought in from some more remote sources.

The present population of this region including San Francisco, but not including the east bay region northerly from Haywards, is about 530,000. What the population may be in a half century can only be conjectured. It will probably exceed 1,500,000; and within 100 years it may reach 5,000,000.

Accepting 100 gallons per day(extreme economy being assumed) as the requirement per inhabitant of this region for all purposes,excepting farm irrigation,the consumption may reach 150,000,000 gallons per day in 50 years and 500,000,000 gallons per day in one hundred years, besides some requirement for irrigation of farm products.

Without any regard to the fact that some of the water from Coast Range areas may be much less

desirable for human consumption and general domestic use than water from high mountain regions it is manifest from these figures compared with the runoff noted in Table XVII that a time will come when -quantity alone being considered- the sources of water near San Francisco on the bay slopes of the Coast Range will be inadequate.

The only other nearby water that can perhaps be obtained is the water of Pescadero and other ocean slope creeks, if it be assumed that water which should in large part be conserved for the use of the coast areas of San Mateo County can ever be diverted for use by San Francisco or other bay cities.

When it is made apparent, however, as by the analysis in the preceding pages, that San Francisco must some day, alone, or in co-operation with her neighbors, go to some remote source such as the Sierra Nevada for the major portion of her water supply, then it would seem proper that this should be done first, before attempting at relatively high cost to add ocean slope water which may in the meanwhile become equally valuable in the development of other communities. Although, therefore, some consideration may be given to the possible water development on the ocean slope of the peninsula, particularly as rights to the water of some of these streams have long been claimed by the Spring Valley Water Company, yet these sources, perhaps with equal propriety, could be

considered as too doubtful to be regarded as available. Their productiveness as sources of water, under the assumption of a general outline of a project for the development of their water will be considered in a separate chapter.

The runoff as noted in Table XVII includes all the present water consumption for domestic purposes and for irrigation, as well as the water which actually reaches the sea.

Unless additional water is brought into the bay regions from remote sources, this runoff properly conserved will be called upon to meet the future requirements of a centrally located section of the State which is capable of the highest development.

Some of this water, about 33,000,000 gallons per day, is used in San Francisco, some is taken from the deep wells at Alvarado for use in Oakland and neighboring cities, some goes to supply San Jose, Santa Clara, Redwood City, San Mateo, Palo Alto, Los Gatos, Niles, Pleasanton, Livermore, and the many other towns and villages within the watershed of the South Arm of San Francisco Bay; some makes its appearance in the artesian wells from which there is considerable irrigation in the Santa Clara Valley and particularly near Alviso; and some of it is pumped from the ground, being taken from thousands of wells by pumps of all manners of capacities, to supply domestic needs and often too for irrigation. The rest flows into the bay mainly at the freshet stages of the creeks.

The visible runoff from the level land below the margin of the hills in Santa Clara Valley and upon both sides of San Francisco Bay as far northerly as Haywards on the east side and San Francisco on the west side, is not subject to interception for storage in reservoirs. There are no reservoirs feasible on the flat valley lands. No part of the runoff originating on this area, except only that which may sink into subsurface gravel or sand strata, can be made available. During years of moderate rainfall(most years bringing to this area less than 20 inches of rain)there is no runoff. The water is held by the surface soils, sustains plant life and is evaporated. During the occasional wet years which are mainly responsible for the runoff included for this area in the table there may be a surplus of water on the surface, of which some sinks into the ground beyond the reach of evaporation,while the rest is waste. Little, if any account, should therefore be taken of the runoff from this area in estimating the available supply. Exception to this rule may, however, be made in the case of special studies of known areas of gravel of large extent, such as the Niles Cone.

In order to show the probable limit beyond which no development will ever carry the aggregate water production within the entire area under consideration the 80 per cent factor of utilization, as already explained, may be applied to the runoff from the hill areas and enclosed valleys excluding from consideration only the flat

land in lower Santa Clara Valley and upon both sides of the Bay.

The flat land thus excluded has an area of about 384 square miles and the normal runoff from this area computed from the curves as shown on the runoff map is about 36,000,000 gallons per day. Nearly all of this, as stated, will be wasted.

Following is a condensed summary from Table XVII:

Runoff,	Alameda Creek at S.F.Bay	137,300,000	gals.per day
"	Coyote Creek " " " "	136,400,000	" " "
"	Guadalcupe R. " " " "	74,200,000	" " "
"	Portola Reservoir watershed	7,300,000	" " "
"	Peninsula Reservoirs Crystal Springs, San Andres, Pilarcitos	28,300,000	" " "
"	Miscellaneous creeks and lands at S. F. Bay	36,600,000	" " "
	Total,	413,100,000	" " "

To the question "How much of this water will be required for the needs of communities and lands outside of San Francisco" no precise answer can be given. There are over 300,000 acres of valley land within the watershed. On this area the normal rain is less than 20 inches per year. Whether cultivated for ordinary farm products or for fruit or vegetables, seeds or flowers, this land needs water in addition to the rainfall to make it reasonably productive. One half to two thirds of this land, or 100,000 to 135,000 acres, may retain its rural character. The water that can be beneficially used on

these 100,000 to 135,000 acres for irrigation alone will amount to 150,000 to 200,000 acre feet per year, or from 130,000,000 to 180,000,000 gallons per day.

The population of the region under consideration, not including San Francisco, now somewhere near 120,000 may be doubled every 30 years, or perhaps even more frequently. Most of this population is urban being concentrated in the cities and towns- San Jose, San Mateo, Redwood City, Palo Alto, Livermore, Pleasanton, etc. Within 50 years the consumption of water for ordinary domestic purposes within this region may readily reach 35,000,000 million gallons.

With these facts in mind the following apportionment of the runoff from the area tributary to the South Arm of San Francisco may be made.

Total Runoff		412,100,000 gals.per day .
Deduct runoff from watersheds of the Crystal Springs, San Andres and Pilarcitos reservoirs-		28,300,000
Leaves-		383,800,000
Non-available(valley land runoff)		36,000,000
Remainder-		347,800,000
Ultimate utilization at 80%		278,000,000
Irrigation may require, say,	180,000,000	
Domestic use outside of San Francisco about 1960	35,000,000	215,000,000
Leaving available for development for use in San Francisco and other Bay Cities,- including the water already developed on Alameda Creek,		63,000,000
There is already developed and being used in San Francisco a supply from Alameda Creek amounting to about		15,000,000
Leaving as the amount that may be considered available for future development for use in San Francisco to 1960		48,000,000

Any taking of water from this watershed in excess of this amount for use in San Francisco or for use in other cities outside of this territory would be to the detriment of other communities equally worthy of full development. The 51,000,000 gallons per day, or some other amount similarly determined is to be accepted as the limit of the supply that San Francisco should ever hope for under the most favorable conditions of utilization, from the areas now under draft and from possible extensions of works in the bay watershed.

It may be repeated that it may be impossible to ever attain as high a factor of utilization of runoff as the 80 per cent which has been introduced into the calculation. For this reason it is believed that though this may be the actual outcome of water development, a less favorable outcome than the above figures should be regarded as not impossible unless a material inroad upon the needs of other communities and rural districts be sanctioned.

In this presentation there has been no consideration given to the quality of the water. It may be assumed that only such portions of the runoff will ever be stored or otherwise brought under control for domestic use as are naturally wholesome or can be made so by ordinary treatment - such as filtration. Neither has any reference been made to cost, because the sole endeavor has been to approximate the upper limit of possible water development in order that it may be apparent that San Francisco must at some time go to remote sources for the main portion of her water.

With reference to any selected portion of the bay watershed the rainfall and runoff map may be used to forecast the water production in the same way that it has been here used in discussing the whole area.

For example, the total normal runoff from the 398 square miles tributary to the Laguna Creek at the gorge below Pleasanton is 54,600,000 gallons

per day. When some of this water is stored in reservoirs on Arroyo Valle and on Arroyo Mocho and their tributaries there will be some loss by evaporation. Of the remainder some, at times of heavy freshets, will flow to waste down Laguna Creek and past the Sunol Dam. If under these circumstances a utilization of 80 per cent of the runoff can be attained this will amount to 44,000,000 gallons per day. Of this water some is already developed for local use at Livermore and at Pleasanton and at the many private wells throughout Livermore Valley, and about 7,000,000 gallons per day, secured from the Pleasanton wells, are being delivered to San Francisco. If the total consumption from this source is now about 8,000,000 gallons per day, which seems probable, there remain 36,000,000 gallons per day yet to be made available. A part of this may be secured by increasing the output of the wells at Pleasanton and the rest by storage works in the mountains which may possibly be used in whole or in part to reinforce the inflow into the water bearing gravels of Pleasanton Valley.

But no matter what these works may be, a limit may readily be determined beyond which no further development should be expected. Moreover if all of the additional 36,000,000 gallons per day be made available for San Francisco's use, this can only be done by restricting the growth of the towns and by restricting agricultural development on the 40,000 acres in the Livermore Valley.

As another illustration: It will be found from the runoff map, Fig. 14, that the normal flow through Calaveras Valley is 35,100,000 gallons per day and that the normal flow of Alameda Creek(formerly Arroyo Hondo) which may in part be diverted into Calaveras Valley is 11,300,000 gallons per day.

The evaporation from a reservoir in Calaveras Valley, if a water surface averaging 1500 acres and an annual evaporation of 3,5 ft.be assumed, will be,as already stated, 4,650,000 gallons per day(average)or about 13 per of the normal runoff from the Calaveras Creek watershed. The evaporation of Calaveras Creek water together with other losses should not be assumed at less than 20 per cent.

The upper Alameda Creek is to be made indirectly tributary. Ordinarily the factor of utilization in such a case would be relatively low, but in view of the short canal required to effect the diversion and the relatively low rainfall in the creek's drainage basin, here also the factor 80 per cent may be introduced.

Water development, by storage in the Calaveras reservoir, in excess of 80 per cent of the total runoff of both creeks, 46,400,000 gallons per day, or about 37,100,000 gallons is not probable. This amount may be exceeded for short periods but more should not be counted on in the long run.

A production of 37,100,000 gallons on the Calaveras Creek and nearly the same amount on Laguna Creek and its tributaries would exceed the amount of ultimate

expansion, which as has been pointed out, can be made without interfering with local development in the south bay region.

In the ultimate project if the Spring Valley Water Company works are to be expanded to their practical limit it seems probable in the light of these facts that the possibilities in the areas above Pleasanton should not all be credited as available for San Francisco. The development on the Calaveras may, on the other hand, be pushed to the limit for this city's benefit including development of water by storage on San Antonio Creek and a maximum storage in the gravel beds of the Sunol Valley. The extension of the works on this branch of Alameda Creek will interfere much less with local interests than would be the case if the maximum possible draft were made upon the Laguna Creek drainage basin.

In noting the present utilization of Alameda Creek water at 15,000,000 gallons per day only the amount which the Spring Valley Water Company diverts for use in San Francisco was taken into account. To this there should perhaps have been added all local consumption of water in the Livermore Valley and on the Niles cone and also the output of the Alvarado wells. But this has not been done for the reason that this may stand as an offset to the filtration of rain into the Niles cone which at variance with the runoff from other flat areas around the bay is, in part, available for utilization.

Enough has been said to show that all of the water originating in the watersheds of the

streams which enter the Santa Clara Valley should ultimately be used locally, that none of it should be regarded available for use in communities far removed from the upper end of San Francisco Bay and that when so used there will be more or less interference with the development of local resources.

It follows from this that the artesian waters at and near the southerly end of San Francisco Bay should not be regarded as an available source of water for San Francisco nor as available for any permanent contribution of water. The most that might be expected from this source is an emergency development which could perhaps, in some measure, for a brief period of time safeguard the supply from other sources. But even the availability of wells in this locality for such a purpose remains to be demonstrated.

It is not known what the maximum amount is that could be obtained from this source by means of an adequate system of wells, nor can the extent be foretold to which a large draft upon the subsurface storage would affect the large number of wells already in use near the bay and in the Santa Clara Valley. It is certain that during the greater part of the year any draft approximating the requirements of San Francisco would be a draft upon the stored subterranean waters and would if continued long enough materially affect the condition of the wells in Santa Clara Valley.

Ample evidence of the interdependence

of the wells in this valley is available. Soon after some of the strongly flowing wells near Alviso in the lower end of the Santa Clara Valley were opened many years ago, it was found that the flow of the wells near San Jose decreased and some wells in that city ceased to flow altogether. Ordinances were thereupon passed to compel owners of artesian wells to check the flow when water was not being used. These laws were intended to prevent waste. Most of the wells in the lower part of the valley are 250 to 500 feet in depth, and the water rises from one or more layers of sand and gravel lying between beds of clay. These wells show a direct connection with the sources of supply which lie at the valley's edges. As illustrating this point the San Jose Mercury of April 12th, 1884, may be referred to. It contained the information that the flow of the artesian wells in the eastern part of the valley was increasing every day; that the wells which had gone dry and in which water sank to several feet below the surface were flowing again. The well of Mr. J. Lee on Santa Clara Street was referred to as a good example of a well which has commenced to flow again and the view was not expressed that recent rains were the cause of the increased flow.

The availability of ocean slope streams has been briefly alluded to in the foregoing pages. This subject will now be given some further attention and incidentally some additional facts will be presented relating to the runoff from areas tributary to the Pilarcitos and San Andres reservoirs of the Spring Valley Water Company's system.

CHAPTER IV.

THE AVAILABILITY OF PESCADERO CREEK, SAN GREGORIO CREEK, AND OTHER OCEAN SLOPE CREEKS AS SOURCES OF WATER FOR SAN FRANCISCO.

THE AVAILABILITY OF PESCADERO CREEK, SAN GREGORIO CREEK AND OTHER OCEAN SLOPE CREEKS AS SOURCES OF WATER FOR SAN FRANCISCO.

By

C. E. Grunsky, Consulting Engineer.
1911.

Somewhat further away from San Francisco than the peninsula reservoirs from which the Spring Valley Water Company obtains about one half of the water now being supplied to the City are a number of creeks which flow westerly from the Coast Range into the Pacific Ocean.

The most important of these creeks when considered only with regard to volume of flow are the Pescadero Creek and San Gregorio Creek.

Pescadero Creek at a point just below Peters Creek has a watershed of 39,5 square miles. As a source of supply by gravity flow only that part of Pescadero Creek comes under consideration which lies above 400 feet in elevation. That part of the creek below this elevation is in a narrow canon not widening out until elevations approximating 100 feet above sea leval are reached.

A diversion of water from Pescadero Creek for use upon the east side of the Coast Range could be made just below Peters Creek. The elevation of the creek is there somewhat below 400# feet,but a fairly high dam is feasible.

(#) All elevations are given above mean sea level.

The watershed southerly from the main channel of the creek is timbered. Northerly from the main creek the watershed tributary directly to the main creek and indirectly to it through Peters Creek has a forest cover in the canons and generally well up on the slopes but the hill tops are bare. About one-third of the entire watershed above the proposed dam site may be classed as being either forest or brush covered. All is mountainous but the hills and mountains are nearly all soil covered and have gently rounded summits falling off quite steeply into the deeper ravines. The water courses are closely hemmed in by the mountain slopes. There are no open valleys on the creeks above the junction of Peters Creek with the Pescadero. The timber is mostly redwood with some oak, Douglas spruce, madrono, etc.

There is some farming on the watershed and some cutting of wood for railroad ties and fence posts about a mile and a half north of the Pedcadero on a tributary of Peters Creek. Split redwood ties are being taken out from here for the Santa Fe (in 1911)

The rainfall on the watershed of the Pescadero is normally somewhat in excess of 45 inches. There is a record of rain available for only a single station within the watershed but from many records on the peninsula southward from San Francisco and a thorough study of rain dis-

tribution it appears proper to accept the amount named as the ordinary amount of rain to be expected in a season. A full discussion by the writer, of rain distribution in this region is to be found in Transactions of the American Society of Civil Engineers, Vol. LXI, page 496.

The San Gregorio watershed of 21.1 square miles above a possibility gravity diversion is a region of soil covered hills with comparatively steep slopes toward the creek and its tributaries. There is no widening out into flat valleys on this stream or its tributaries at elevation above the 400 foot contour.

San Gregorio is formed by Alpine and La Honda Creeks which unite about one half mile below La Honda Hotel. The canyons are timbered--redwood, Douglas fir, madrono, oak, etc. The timber and brush covered areas extend in many places well up toward the flatter upper slopes of the mountains. The hill tops and upper slopes are generally bare. Some of the bare land is farmed to hay and grain. Some farming was seen on steep hillsides that would generally be regarded as impossible. Rather less than one-third of the watershed of the creek above La Honda and Alpine junction is timbered and brush covered.

The elevation of the watershed under consideration ranges from 400 to 2500 feet. The summit of the main ridge is from 1500 to 2500 feet in elevation. The watershed extends to the crest of the Coast Range and lies along the same for a distance of about 8 miles.

The rainfall upon the watershed is generally about 40 inches. No records of rain within the basin are available but a careful analysis of records over a broad area southward from San Francisco to Santa Cruz indicates this amount. The rainfall study as published in the Transactions of the American Society of Civil Engineers, Vol. LXI, page, 198, is to be referred to in this connection.

Along the La Honda is the road from Redwood to San Gregorio. It drops down from the summit into the creek gorge and follows the creek. There are a number of attractive camping places along the creek at and above, a few also below La Honda. The Woodruff Hotel(new about 1909) is about two miles above La Honda. Some hundreds of people are along the creek in the summer months. About 300 are claimed to be near the La Honda Hotel at the height of the season in summer. There were probably more than 100 near La Honda in the latter part of July 1911.

Corte Madera Creek drains a watershed of 7.7 square miles above a possible gravity diversion. This creek is northwesterly from La Honda Creek and its watershed has the same general characteristics of the watersheds of Pescadero and of San Gregorio Creeks. The timbered and brush covered area is probably less than one-third of the entire watershed.

Bogess Creek drains a watershed of 2.4 square miles lying just east of Corte Madera Creek.

Its watershed does not extend up to the summit of the main ridge.

Harrington Creek drains a watershed of 4.0 square miles lying between that of Bogess Creek and La Honda Creek. The watershed is long and narrow but does not extend quite to the summit of the range.

These five creeks drain portions of the Coast Range which in the matter of elevation and mountain forms, soil and forest cover are similar to the region which is in part naturally and which has been made in part artificially tributary to the Pilarcitos and the San Andres reservoirs of the Spring Valley system. It is known too that in the matter of annual rain there is no great difference. Consequently the fact that the watersheds of the established reservoirs are good water producers has long been accepted as conclusive evidence that large amounts of water could be obtained from the ocean creeks.

As early as 1872 water rights and privileges on these creeks were offered to the Spring Valley Works, the predecessor of the present water company and some investigations were made by the engineers of the company. In 1874 Mr. T. R. Scowden in his report to San Francisco upon available sources of water gave these creeks some attention. Mr. Scowden referred to the watershed of Pescadero Creek as a densely wooded country. He outlined a project involving a dam on Pescadero Creek about one quarter mile

below Peters Fork. The dam was to have a height of 90 feet and it was estimated that it would impound 600,000,000 gallons of water.

Water was to be carried from the reservoirs this constructed, by aqueduct and tunnels, crossing and taking up the waters of San Gregorio, Bogas, Alamo and Tunitas Creeks, into Canada Raymundo now a part of the Crystal Springs reservoir.

The aqueduct as planned had a length of 22 miles and a capacity of 135,000,000 gallons. per day, it being recognized to be desirable to intercept as much as possible of the flood flow of the winter months. The creeks have only a small flow in summer and fall. Mr. Scowden estimated the minimum summer flow of the creeks as follows:

Pescadero Creek,	2,434,100	gals.per day
San Gregorio Creek,	1,415,800	" " "
Bogas & Alamo Creeks,	486,800	" " "
Tunitas Creek,	486,800	" " "
Total,	4,822,900	" " "

He assumed that 62 days could be counted on as supplying enough water from these creeks to fill the proposed conduit and that there would be 8 months with a flow of only 5,000,000 gallons per day. In the remainder of the year the aqueduct would carry from 5,000,000 to 135,000,000 gallons per day.

Mr. Scowden also pointed out the possibility of storing some water at low levels in a reservoir on Pilarcitos Creek and pumping the same up into the

high line aqueduct.

In the fall of 1872, at the time that the Spring Valley Water Works had the purchase of the properties of the Pescadero Water Company under consideration, a gaging of Pescadero Creek was made just below Peters Fork by Messrs. R. Abbey and W. H. Lawrence of which Mr. Abbey says:

"We placed a weir in the creek at "this point and found a flowage of 24 by 6½ inches on "very nearly 1,700,000 gallons in 24 hours."

About the 1st of November in 1872 a gaging was made near the same point by Mr. H. Schussler and General B. S. Alexander and they reported 3,100,000 gallons of water in 24 hours, flowing in Pescadero Creek.

In 1876 the availability of the ocean slope creeks as a source of water for San Francisco was discussed by Col. G. H. Mendell, who at that time made an exhaustive investigation of the San Francisco Water Supply problem.

Col. Mendell in his report referred to the favorable character of the watershed of these creeks from the Tunitas southward to the Pescadero. He speaks of the Sierra Morena, whose western slope these creeks drain, as a high well-timbered range of mountains. He did not make low water gagings but refers to the measurement made by Mr. T. R. Scowden several years before and stated that on May 31st 1876 the San Gregorio Creek discharged about 5,000,000 gallons of water per day and the pescadero Creek about 8,000,000 gallons. There is no doubt, he says, that the

creeks later in the season carry much less water.

During this season(1911) the writer has made gagings with the following results:

TABLE XIX

Coast Stream Gagings.
1911

Date	Creek	Location	Discharge Sect. Feet	Water Shed Area Sq.Mi.	Runoff per Square Mi. Sec. Feet.
July 25,1911	La Honda	At La Honda Hotel	2.59	10.7	0.24
" 26, "	"	"Jct.with Alpine Creek	4.11	11.8	0.35
" 27, "	"	" " "	4.78	11.8	0.41
" 26, "	Alpine	Jct.with La Honda Creek	3.92	9.4	0.42
" 25, "	San Gregorio	Below Jc. of Alpine & La Honda	6.61	21.2	0.32
" 25, "	Corte Madero	At Creek Haymond Place	2.50	7.7	0.33
" 26, "	Peters	At Jct.with Pescadero Creek	5.41	9.8	0.55
" 26, "	Pescadero	Above mouth of Peters Creek	7.68	19.4	0.40
" 26, "	"	Below Peters Crk. (By addition)	13.09	29.2	0.45
Oct 19, "	- "	Below Peters Crk.	5.33	29.5	0.180
" 20, "	San Gregorio	" Jct.of Alpine & La Honda	3.53	21.1	0.119

It is to be noted in this connection, however, that the year 1911 is an unusually prolific producer of runoff waters. The rainfall continued late in the spring and the spring months were damp and cold. At the end of the rainy season the soils were well filled with water. All springs were flowing more than in ordinary seasons.

These gagings are of value first, in showing the decrease of flow from the latter part of July to the latter part of October and second, in showing the amount of runoff to be expected at a low stage of the creeks as in October 1911 after a cold wet spring.

In this year, in October, the runoff from the watershed of the Pescadero Creek above the point where a gravity diversion could be made was about 118,000 gallons per day per square mile. At the same time the production of the watershed of San Gregorio Creek was about 77,000 gallons per day per square mile. These amounts probably represent about the lowest runoff for the season. They may, however, have been affected by a light rain which fell in the early part of October. It must be assumed that in years with less rain in spring than in 1911 and with an earlier cessation of the rainy season low water runoff rate would be considerably less than the amounts above noted for 1911.

It is plain in any event that the creeks have a long low water period in the summer and fall of each year and that a high utilization factor for their

waters can not be realized without storage.

The western slope of the Sierra Morena is steep. The creeks which drain this slope have a rapid fall in their upper portions and there are no good reservoir sites to be found on the ocean slope in which to impound the flood flow of these streams at elevations high enough to make the water available by gravity flow for use in San Francisco. The project for a utilization of the water from the Coast streams therefore necessarily involves storage elsewhere than in their own drainage basins and conduits of large capacity become necessary in order that any considerable portion of the winter runoff may be conveyed to storage sites.

The best method of conserving a fair amount of the flood flow of the Coast streams is without question by diversion through the mountain range into the basins already occupied by reservoirs upon the eastern slopes of the mountains.

Such a project is feasible and the Crystal Springs Reservoir of large capacity and with an inadequate watershed is available as a recipient for any water that may be brought into it from the ocean slope of the mountains.

There is, as has already been pointed out in a separate chapter of this report, some doubt relating to losses of water from the Crystal Springs Reservoir and there appears to be a probability that there

is some loss of water by leakage. But even if this is the case it is to be assumed that the raising of the Crystal Springs dam to the proposed ultimate height of 389 feet and the more efficient utilization of the reservoir, by a heavier annual draft upon the same, would not materially increase the aggregate losses, excepting only those which are due to evaporation from the increased water surface.

The feasibility of using Crystal Springs reservoir for the impounding of the waters of the Coast streams has been recognized by the various engineers, Mr. T. H. Scowden, Col. C.E. Grunsky, Mr. H. Schussler who have given this matter some attention in the past. Moreover the capacity of the Crystal Springs reservoir can be made adequate to receive the waters that can be intercepted from the creeks.

The present capacity of the reservoirs at elevation 380 feet is 18,914,000,000 gallons. By raising the dam to a height such that the water surface will be at 389 feet the capacity will be increased to about 45,000,000,000 gallons. The operation of the fully developed system, finally, can be such that the utilization from the reservoir will leave space for the winter inflow.

In order to determine how much water can be intercepted from that part of the ocean slope readily commanded by an intercepting conduit a study has been made with some care relating to the productiveness of the areas which are tributary to the Pilarcitos and the San Andres reservoirs. Three year's seasons were selected for this

study, one being a year with about normal weather conditions, a second being a year with copious rain, about 34 per cent in excess of normal, and the third a year with light rainfall, about 51 per cent of the normal.

The results of this study were appended hereto as a separate chapter. It need be here noted merely that the well known fact that there are about 70 rainy days in the year, in this part of California is confirmed as shown by Diagram, Fig. 24 and that in the three years,(See Figs. 25-27) there were from 3 to 73 days per year on which the runoff exceeded 1,500,000 gallons per square mile.

It will be seen from the Rainfall and Runoff Map, Fig. 14, that the normal rain is somewhat less on the watersheds of the creeks under consideration than on the area which is tributary to the Pilarcitos and San Andres Reservoirs. A comparison of the water productiveness of the several watersheds has been made as below explained.

By use of the runoff curve, Fig. 10, and the normal rain in the watersheds of each of these creeks the results found in Table XX are obtained. The rainfall noted in the table is assumed a little below the amount indicated by the curves on the rainfall map, because these are, on the ocean slope, largely based on conjecture.

TABLE XX

The Runoff from Coast Stream Watersheds compared with the Runoff from the Watersheds of Pilarcitos and San Andres Reservoirs.

Watershed	Normal-Annual Rain- Inches	Corresponding Annuel Runoff Inches	Percentage of Pilar.& S.A. Runoff
Pilarcitos & San Andres:	48	20.5	100
Pescadero	45	17.7	86
San Gregorio	40	13.6	66
Harrington	37	11.3	55
Bogess	34	9.5	46
Corte Matera	35	10.0	49
Coast streams combined			73

The percentage noted in this table for the combined watersheds of the Coast streams is obtained by giving weight to the individual percentages according to drainage areas which are as follows:

Pescadero Creek just below the mouth of Peters Creek,	29.5 sq.mi.
San Gregorio Creek just below the junction of La Honda and Alpine Creeks,	21.1 " "
Harrington Creek,	4.0 " "
Bogess Creek,	3.4 " "
Corte Madera Creek,	4.0 " "

By constructing with the aid of the percentage values noted in Table XX curves similar to those shown in Figs. 35 to 47 it has been possible to prepare the additional Tables XXI, XXII, XXIII, XXIV, XXV, and XXVI.

TABLE XXI

PESCADERO CREEK WATERSHED-29.5 Square Miles.

Runoff during three years.

Amount Million Gals. per square mile per day	Number of days 1894-95 Rain 134 per cent of normal	1896-97 Rain, normal	1897-98 Rain 51 per cent of normal
Less than .25	199	186	298
More " .25	166	179	67
" " .50	120	133	26
" " 1.00	74	84	4
" " 2.00	32	50	1
" " 5.00	12	11	0
" " 10.00	3	3	

TABLE XXII

San Gregorio Creek Watershed- 21.1 Sq.Miles.

Runoff during three years.

Amount Million Gals. per square mile per day	Number of days: Rain 134 per cent of normal 1894-95	Rain normal 1896-97	Rain 51 per cent of normal 1897-98
Less than .25	210	200	323
More " .25	155	165	42
" " .50	109	118	16
" " 1.00	56	73	3
" " 2.00	24	30	0
" " 5.00	10	8	
" " 10.00	0	0	

TABLE XXIII

Harrington Creek Watershed- 4.0 Sq.Miles.

Runoff during three years.

Amount Million Gals. per square mile per day	Number of days: 1894-95 Rain 134 per cent of normal	1896-97 Rain-normal	Rain 51 per cent of normal 1897-98
Less than .25	215	216	330
More than .25	150	149	35
" " .50	96	106	11
" " 1.00	43	59	1
" " 2.00	21	22	0
" " 5.00	6	5	
" " 10.00	0	0	

TABLE XXIV

Bogess Creek-Watershed 2.4 Sq.Miles.

Runoff during three years

Amount Million Gals. per day per sq. mile.	Number of days 1894-95 Rain 134 % of normal	1896-97 Rain Normal	1897-98 Rain 51 % of normal
Less than .25	233	233	336
More than .25	132	132	29
" " .50	79	88	5
" " 1.00	34	45	1
" " 3.00	19	15	0
" " 5.00	3	4	
" " 10.00	0	0	

TABLE XXV

Corte Madera Creek Watershed 9.8 Sq. Miles.

Runoff during three years

Amount Million Gals. per day per sq. mile.	Number of days Rain 134% of normal 1895-96	Rain-normal 1896-97	Rain 51% of normal 1897-98
Less than .25	224	229	334
More than .25	141	136	31
" " .50	82	98	7
" " 1.00	36	48	1
" " 3.00	19	17	0
" " 5.00	3	5	
" " 10.00	0	0	

TABLE XXVI.

Ocean Slope Creeks-Pescadero to Corte Madera (Combined) Watershed 64 Sq.Miles.

Amount Million Gals. per day per sq. mile.	Number of days 1894-95 Rain 134% of normal	1896-97 Rain-normal	1897-98 Rain 51% of normal	Average
Less than .25	303	195	309	236
More than .25	162	170	56	129
" " .50	113	125	18	85
" " 1.00	60	77	3	47
" " 2.00	26	34	1	20
" " 5.00	11	9	0	7
" " 10.00	1	0		0

Based on Table XXVI on the assumption that normal conditions will be fairly represented by averaging conditions as they prevail in the three selected years, it has been possible to prepare Table XXVII which shows in the last column the amount of water that without recourse to storage could be intercepted with a conduit having a capacity of 125,000,000 gallons per day.

TABLE XXVII

Ocean Slope Creeks-Pescadero to Corte Madera
Watershed 64 Sq.Miles.

Available Runoff, without storage-Conduit capacity 135,000,000 gals. per day.

Number of days	Amount-Million Gallons per square mile per day	Amount Million Gals.per day from 64 sq. miles	Amt.interceptable Conduit capacity 135 million gallons per day
236	Less than .25 = .100	6	6
44	.25 to .50 = .375	24	24
38	.50 to 1.00 = .750	48	48
27	1.00 to 2.00 = 1.500	96	96
13	2.00 to 5.00 = 3.750	240	135
7	5.00 to 10.00 = 7.500	480	135
365			25.7

It will be observed that for the 236 days with runoff less than 250,000 gallons per day per square mile, the average has been inserted in the table at 100,000 gallons per day. This amount is probably an over-estimate for some seasons but can not be far in error. It results from the assumption that ordinarily there will be 5 months in the year with a runoff of about 75,000 gallons per day per square mile (4.8 million gallons from the entire 64 square miles) and that during about 2 other months the runoff will range from 100,000 gallons to 250,000 gallons per day per square mile.

It appears too that ordinarily there will be only about 20 days in which the runoff from all the coast streams exceeds 135,000 gallons per day. It would be inadvisable to construct a conduit of larger capacity. At the same time there is a large surplus flow during one or two of the annual high water stages of the creeks, and this can be conserved in part by storage. How much can be thus added to the interception of natural flow is dependent upon the capacity of reservoirs that might be constructed on the Pescadero Creek and on the San Gregorio. It appears possible to hold back some water on the Pescadero, where this is of greatest importance by reason of the large watershed of Pescadero Creek; and to a lesser extent too on the San Gregorio. Reservoirs on these streams would in some seasons be repeatedly filled. It seems probable that the effective storage of 1470 million gallons, as below noted, for the two reservoirs could probably in the long run be made available from one or two times per season. This would add from 1470 to 2940 or on an average about 2200 million gallons of water per year to the aggregate diversion from the coast streams, or 6.0 million gallons per day.

The water production of these streams, without regard to evaporation losses from reservoirs, may therefore be taken into account at about(25.7+6.0) or 31.7 million gallons per day.

By use of the runoff map or Table XVII and the amounts of rain noted in Table XX the normal runoff from the coast stream watersheds, under consideration, is found to be 51 million gallons per day. The utilization factor with intercepting works as proposed would therefore be about 63 per cent.

Expressed in quantity per square mile the coast stream watersheds would produce about 500,000 gallons per day.

The foregoing discussion of the yield of the Coast Range ocean slope creeks to an intercepting canal is of course based on the assumption that their waters are available, without restriction, for diversion into another watershed. It is well known, however, that there are interests in the basins of these streams which would be adversely affected by so complete a diversion of their waters.

As the population along the ocean shore southward from San Francisco increases and the cultivation of the arable soil which covers the lower hills of the region in question is extended there will be an increasing demand for water, for both domestic use and for the irrigation of truck gardens. It is difficult to set a limit to the amount of water that will ultimately thus be required but account should be taken of the fact that this region is one of considerable promise, that it already has been made accessible in part by a railroad from San Francisco and that the watersheds of the ocean

creeks are the natural and only known sources of water on which this region may draw for its requirements.

The project as here discussed has not been extended to include water diversion from Tunitas Creek, from Purisima Creek nor from the lower tributaries of Pilarcitos Creek because the areas that can be commanded on each of these watersheds by any inceptor not fed with pumps is relatively small and because the aggregate area that could be brought under contribution on these streams by long and expensive conduits is only about 20 square miles.

However in a consideration of the extreme limit of possible water production this area might be entered at 400,000 gallons per square mile (the same as the other coast stream watersheds without any allowance for equalizing storage), or a total of 8,000,000 gallons per day.

The region from which a collection of this water is to be regarded as possible is of a mountainous character. Long spurs extend westerly from the main range between each of the creeks and between the smaller tributaries to the creeks, rendering the collection of this water difficult and expensive. There would be much tunneling required.

The possible water production of the coast streams indicated by the foregoing analysis

does not take into account the evaporation loss that must be expected, when the water is held in storage for any length of time. The present area of the water surface of Crystal Springs Reservoir when full is 1300 acres. If the dam should be raised 40 feet the area of the full reservoir would be 2300 acres. When used as a recipient for Coast stream water there will be about 1000 acres more water surface exposed to evaporation than at present. The evaporation loss at 3 feet per year will be increased by about 3000 acre feet or about 2,700,000 gallons per day. This amount should be taken into account in determining the net productiveness of the ocean slopes of the Moreno range of mountains.

General Features of a Coast Stream Project.

Subject to various possible modifications in the alignment of conduits and particularly of the tunnels that will be required to pierce the ridges that lie between the creeks and of the main tunnel which will be required to carry the water under the Moreno range, the project for the utilization of the coast streams from the Corte Madera southward to the Pescadero may be briefly outlined as follows: (See Fig. 15)

There would be a dam about 100 feet high probably of earth with a concrete core on Pescadero Creek somewhat less than one half mile below the mouth of

Peters Creek(Peters Fork). The reservoir formed by this dam would have an effective storage capacity of about 1,000,000,000 gallons. From above this dam there would be a conduit for the most part on the slope of the mountains about 4.2 miles long to Jones Gulch and then a tunnel 1.8 miles long to San Gregorio Creek. The capacity of the conduit between Pescadero Creek and the San Gregorio should be about 100 million gallons per day. Water would be diverted at the Pescadero at an elevation of 400 feet and would reach the San Gregorio at an elevation 382 feet- the fall per mile in the conduit being taken at 3 feet.

At the San Gregorio the water would be received below a dam about 100 feet high and together with the runoff from Alpine and La Honda Creeks would be turned into a tunnel extending in a northeasterly direction under the main range to some point about a mile northeasterly from Portola or Searsville reservoir. At this point the tunnel, with water surface at about 362 feet in elevation would be near enough to the surface of the ground to be constructed in open cut for some distance. Its direction would here change to the northwest and its lower end would be at about elevation 349 (bottom grade) near the southeasterly extremity of the proposed enlarged Crystal Springs Reservoir.

From San Gregorio Creek to near Searsville reservoir the tunnel would have a length of 6.4 miles and thence to Crystal Springs Reservoir, (not deducting anything for a possible open cut) about 4.4 miles.

The capacity of the tunnel from the San Gregorio to Crystal Springs Reservoir should be 135,000,000 gallons per day. For the interception of the waters of Corte Madera Creek and the other creeks between Corte Madera and San Gregorio there would be required a conduit beginning at the Corte Madera with a capacity of 18 million gallons per day, and reaching the San Gregorio with a capacity of 30 million gallons per day.

It is estimated that to bring the Corte Madera, the Bogess and the Harrington Creeks into the San Gregorio there would be required about 2.5 miles of canal and 1.5 miles of tunnel.

ESTIMATE OF COST.

The foregoing analysis would not be complete without some statement relating to the probable cost of bringing the water from the Coast streams into the Crystal Springs Reservoir. The cost of a project as outlined is not the cost of water delivery in San Francisco but would strictly be comparable only with the cost of making any other water available under the storage conditions which would prevail

if the Crystal Springs Reservoir were enlarged as proposed by raising its dam to a height of about 328 feet, or 40 feet above the present crest. (The elevations here noted are above mean sea level) To reduce to Crystal Springs datum, Spring Valley base subtract 3.76 feet)

Dam at Pescadero Creek 100 feet high, of earth including wasteway,.....	$ 400,000.00
Conduit-Pescadero Creek to San Gregorio, capacity 100,000,000 gallons,6 miles long; 1.8 miles in tunnel,.....	740,000.00
Diversion works at Corte Madera,Bogess and Harrington Creeks,.....	75,000.00
Conduit-Corte Madera Creek to San Gregorio capacity 16 to 30 million gallons, 4 miles long including 1.5 miles in tunnel,.....	400,000.00
Dam at San Gregorio Creek 100 feet high,of earth including wasteway,.....	450,000,00
Tunnel from San Gregorio Creek to Crystal Springs 10.3 miles,.....	3,425,000.00
	$5,490,000.00
Interest during construction,incidentals, rights-of-way, etc. about 20%,.....	1,110,000.00
Total,.....	$6,600,000,00

For a total development of 31.7 million gallons per day this would be at the rate of practically $208,000 per million gallons per day, delivered into Crystal Springs Reservoir.

Modifications of the project as outlined are, as has been stated, recognized as worthy of investigation in case that the bringing of the coast stream waters into the Crystal Springs Reservoir is ever seriously

considered. It might be found desirable, for example, to utilize the Portola Reservoir as a storage site and as an equalizer of flow. It seems probable that thereby the required capacity of the conduit from Searsville to Crystal Springs could be somewhat reduced and that it might be possible to improve the location of the suggested tunnel or even to substitute for the tunnel a conduit of greater length on the bay slope of the hills which lie to the eastward of Canada de Raymundo.

It is not essential that such matters be further considered at this time.

The capacity of Crystal Springs Reservoir would have to be increased to receive the water from the coast streams. It is estimated by the engineers of the Spring Valley Water Company that with a water surface of elevation 328 feet the contents of the reservoir would be about 45,000,000,000 gallons. The feasibility of raising the Crystal Springs dam to the height necessary to accomplish this is generally accepted and no reason is apparent why this feasibility should not be assumed for the present purpose without special investigation.

No information is at hand to show what the cost would be of raising the Crystal Springs dam to a height adequate to afford storage space for the coast stream waters. The necessary height of dam would

probably be somewhat less than 40 feet above the present crest.

It is claimed by Mr. H. Schussler consulting engineer of the Spring Valley Water Company and formerly Chief Engineer and Manager, that it would cost about $2,000,000 to raise the dam about 40 feet to elevation 333 feet. It may therefore be assumed that a somewhat less expenditure would meet the requirements for storage of the coast stream waters.

STORAGE POSSIBILITIES.

PESCADERO AND SAN GREGORIO CREEKS.

In connection with any project for the utilization of the waters from the coast streams, Pescadero Creek, San Gregorio Creek and the smaller streams, Harrington, Bogess and Corte Madera Creeks, there will be desirable, as has been stated, some storage of water to equalize in a measure the natural stream flow. This fact was pointed out by engineer T. R. Scowden who reported on the possible utilization of these streams in 1874. He makes the statement that a reservoir with a capacity of 600,000,000 gallons on the Pescadero at the head of the proposed conduit would be feasible.

There are submitted herewith two contour maps Figs. 16 and 17 showing results of surveys made for San Francisco in 1911 both on the Pescadero Creek

at the mouth of Peters Creek, and at the junction of Alpine and La Honda Creek which unite to form the San Gregorio Creek. The contours shown on the diagrams have been carried well above what could be regarded as feasible storage ground in order that expression might be given to the general topographic features of each site.

At Pescadero Creek a diversion at about elevation 400 feet would be desirable in order that adequate fall may be had in the conduit from that point to Crystal Springs Reservoir.

The dam site is in a region of sandstone and shales, where without borings and exploration pits it may be assumed that a dam of moderate height would be quite feasible.

The creek bed about 3300 feet below the mouth of Peters Creek is at about elevation 343 feet.

The survey indicates the following storage capacity for elevations of the water up to 89 feet above the elevation of the creek bed.

TABLE XXVIII.

PESCADERO RESERVOIR SITE - AT JUNCTION WITH PETERS CREEK

Height of Water Surface Above Creek Bed		Area of Reservoir	Contents Above contour 400 gallons
57	400	72	
67	410	94	271,000,000
77	420	119	618,000,000
87	430	144	1,048,000,000

The dam necessary to accomplish this diversion would be about 100 feet high, estimating the height from the creek bed.

The project for utilizing the waters of the coast streams may also include some storage on the San Gregorio. It is possible on that stream either to intercept its two branches, Alpine and La Honda Creeks, separately or by the construction of a dam of some height below the junction to combine with the diversion a small amount of storage.

It will be assumed that the construction of a dam of the necessary height is feasible although this fact has never been definitely determined and would involve a more extended investigation than the circumstances at this time would have justified. If the dam is not feasible the project would only need slight modifications and the water output of the creek would be reduced by several million gallons.

The survey of 1911 indicates a storage possibility on the San Gregorio Creek. Neither the dam site nor the reservoir site are particularly favorable but the advantage of some regulation of the creek flow by storage is recognized as stated. Diverting works with a moderate amount of storage at this point should be preferred to diversion without storage.

The elevation of the creek bed at what would probably be the dam site about 1300 feet below the junction of the two creeks, is about 307 feet. The elevation of the grade line on which waters should be carried to Crystal Springs reservoir is here about 382 feet. Below this elevation the contents of any reservoir should be considered not available.

TABLE XXIX

LA HONDA RESERVOIR.

Height of Water Surface Above Creek Bed	Contour	Area of Reservoir: Acres	Contents Above Contour 330 Gallons.
75	386	75	
80	387	80	124,000,000
85	392	90	[illegible]
90	397	100	418,000,000

The dam to make this storage possible would have a height of about 100 feet above the creek bed.

An an alternative proposition two diverting dams in the two branches of San Gregorio Creek may be considered. If these were used instead of a dam below their junction there would be practically no equalization of the flow of Alpine Creek and very little for La Honda. Somewhat more of the freshet flow of the creeks would flow to waste than if a dam is constructed below their junction.

It is assumed in the analysis of possible utilization of water from the San Gregorio that the storage of 418,000,000 gallons which can be secured with a dam about 100 feet high(above the present surface of the creek bed) will be a feature of the project.

Diversion without any storage is assumed for Harrington Creek, for Bogess Creek and for Corte Madera Creek.

The operation of a collecting system as here outlined will involve storage at periods of highest stages of the creeks of such water only as the creeks bring down in excess of canal capacity. The stored water is to be drawn off at once after the combined flow of the intercepted creeks drops below canal capacity. In this way the reservoirs may according to frequency and intensity of the rain storms be used several times in some seasons.

LAKE MERCED.

Lake Merced which lies within the limits of San Francisco but on the ocean slope of the peninsula has not been included in the foregoing discussion because its waters should be regarded as available for use only in the case of an emergency.

Lake Merced has been contributing some water for many years and has demonstrated its productiveness to be about 3,000,000 gallons per day. This water has been made available by pumping.

The lake as a source of water has been fully discussed in the report of Col. C. H. Mendell (1876) and in the progress report of the City Engineer (Municipal Reports 1900-1901)

CHAPTER V.

THE RUNOFF FROM AREAS TRIBUTARY TO PILARCITOS AND SAN ANDRES RESERVOIRS. 1894-95, 1896-97 and 1897-98.

THE RUNOFF FROM AREAS TRIBUTARY TO PILARCITOS AND SAN ANDRES RESERVOIRS. 1894-95, 1896-97 and 1897-98

By
C. E. Grunsky, Consulting Engineer.
1911.

A special analysis based on the records of the Spring Valley Water Company has been made of the water production of the areas tributary to the Pilarcitos and the San Andres Reservoirs for three selected years, in order that the result of this study might be applied to the watersheds of the coast streams.

Some conclusion concerning the runoff from Coast Range areas in which there have been very few gagings and no continuous records of flow, but for which there may be claimed a fair knowledge of the amount and distribution of rain, can be drawn by applying the results thus determined.

The three years which were selected for special study are: July 1894 to June(inclusive)1895 which was a year of copious rainfall (about 134 per cent of the normal); July 1896 to June 1897 which was a year with about normal rainfall, and July 1897 to June 1898 which was a year with a light rainfall (about 51 per cent of the normal).

The total runoff from the watersheds including the rain upon the water surface of the reservoirs has been determined. When some of the runoff was allowed to flow to waste after the reservoirs were full, the waste was approximated. The approximation was aided by a mass curve of rain and runoff for each of these years Figs. 18 to 20.

From the records of the Water Company the daily gain or loss of water in storage was obtained; also the amount drawn from the reservoirs for use in San Francisco, and the rainfall at each reservoir. The evaporation loss was estimated by the use of the California evaporation curve Fig. 6 and the monthly mean temperatures at San Mateo, in the same way as already explained in the discussion of water loss from Crystal Springs Reservoir.

The total runoff from the watersheds above the reservoir dams, including areas which are made tributary by intercepting conduits, was then estimated for each day by adding together the gain in storage, the draft and the evaporation. When there was a loss of water in storage it appeared as a negative quantity. The evaporation was assumed to take place at a uniform rate during each month.

It would be superfluous to present the results thus obtained for each day in tabular form. They are shown, however, by diagram Figs. 18 to 20. It will suffice to present here a brief summary of the results.

TABLE XVX

SUMMARY

Runoff from the Watersheds of Pilarcitos and San Andres Reservoirs.

Month	1895-96		1896-97		1897-98	
	Rain Inches	Runoff Mil.Gals. per day	Rain Inches	Runoff Mil.Gals. per day	Rain Inches	Runoff Mil.Gals. Per day
July	0	0.25	.05	1.50	0	1.94
Aug	0	0.55	.29	1.11	0	1.55
Sept	3.24	0.46	1.33	1.43	0	1.47
Oct	5.91	2.68	1.93	1.50	4.08	3.04
Nov	1.88	1.53	11.45	.35	3.46	1.86
Dec	21.30	36.51	.51	16.19	4.41	3.88
Jan	19.91	20.23#	3.73	11.15	2.44	3.17
Feb	5.75	11.22#	11.94	46.21	5.15	8.97
Mar	5.37	11.77	1.16	30.43#	1.12	3.02
Apr	3.65	7.62	1.02	14.70	.73	1.96
May	1.03	4.05	.47	5.13	4.13	1.71
June	0	0.97	.46	3.00	1.09	1.04

This does not include waste into ocean nor into Crystal Springs.

The runoff as noted in Table XXX does not include the surplus in excess of reservoir capacities which was allowed to flow down Pilarcitos Creek to the ocean or down San Mateo or San Andres Creeks into Crystal Springs Reservoir. This wasteage is however, taken into account in the preparation of the mass curves of runoff Figs. 21 to 23 and in preparing the curves Figs. 25 to 27 which show the daily runoff arranged according to magnitude.

Referring to Figs. 18 to 20 which show the daily runoff in natural sequence, attention may be drawn to the fact that the fluctuations there appearing in the daily rates during the long period of permanent weather conditions of the summer months, should be disregarded. They result from wind effect upon the reading of the water stage, from the minor inaccuracies of determining the exact stage of the water in the reservoirs, and also from the error introduced by assuming that the evaporation is the same every day in each month, whereas in fact it fluctuates within a wide range.

Table XXXI has been prepared from Figs. 25 to 27 which show the distribution of various runoff rates to the days of the year.

Fig. 24

Diagram Showing

NUMBER OF RAINY DAYS & INCHES OF RAIN PER DAY ARRANGED ACCORDING TO THE AMOUNT OF RAIN PER DAY

PILARCITOS AND SAN ANDREAS WATERSHEDS COMBINED

For the selected Seasons

1894-5 with heavy rainfall
1896-7 with moderate rainfall
1897-8 with slight rainfall

Prepared for the
City and County of San Francisco
by
C.E. GRUNSKY
Consulting Engineer
1911

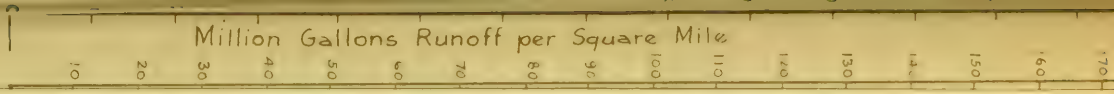

Million Gallons Runoff per Square Mile
10
20
30
40
50
60
70
80
90
100
110
120
130
150
160
170

Fig. 2

DAILY RUNOFF

FROM THE WATERSHEDS OF

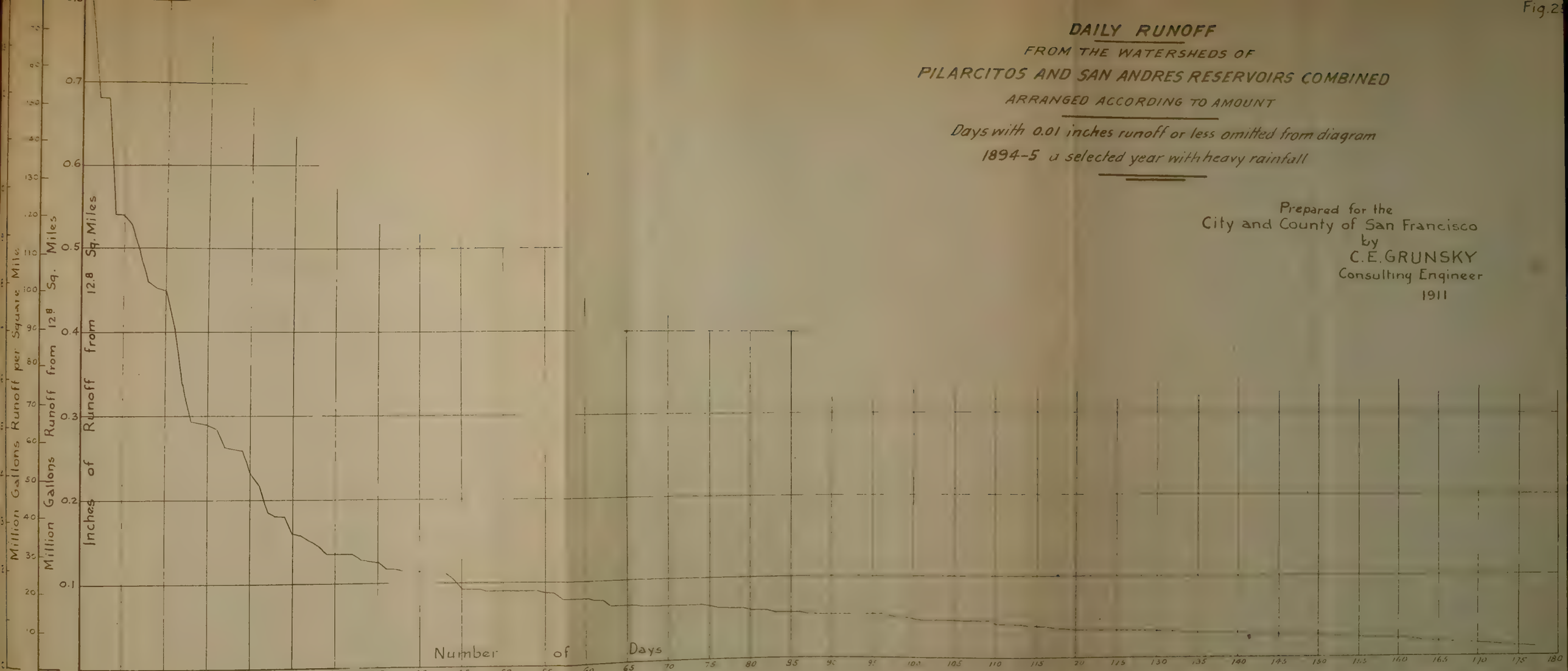
PILARCITOS AND SAN ANDRES RESERVOIRS COMBINED

ARRANGED ACCORDING TO AMOUNT

Days with 0.01 inches runoff or less omitted from diagram

1894-5 a selected year with heavy rainfall

Prepared for the
City and County of San Francisco
by
C. E. GRUNSKY
Consulting Engineer
1911


Million Gallons Runoff per Square Mile
Million Gallons Runoff from 12.8 Sq. Miles
Inches of Runoff from 12.8 Sq. Miles
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Number of Days
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 95 180

Million Gallons Runoff per Square Mile

Million Gallons Pumped per Square Mile
7
6
5
4
3
2
1
0

Fig 27

DAILY RUNOFF

FROM THE WATERSHEDS OF

PILARCITOS AND SAN ANDRES RESERVOIRS COMBINED

ARRANGED ACCORDING TO AMOUNT

Days with 0.01 inch runoff or less omitted from diagram

1897-8 a selected year with light rainfall

Prepared for the
City and County of San Francisco
by
C.E.GRUNSKY
Consulting Engineer
1911

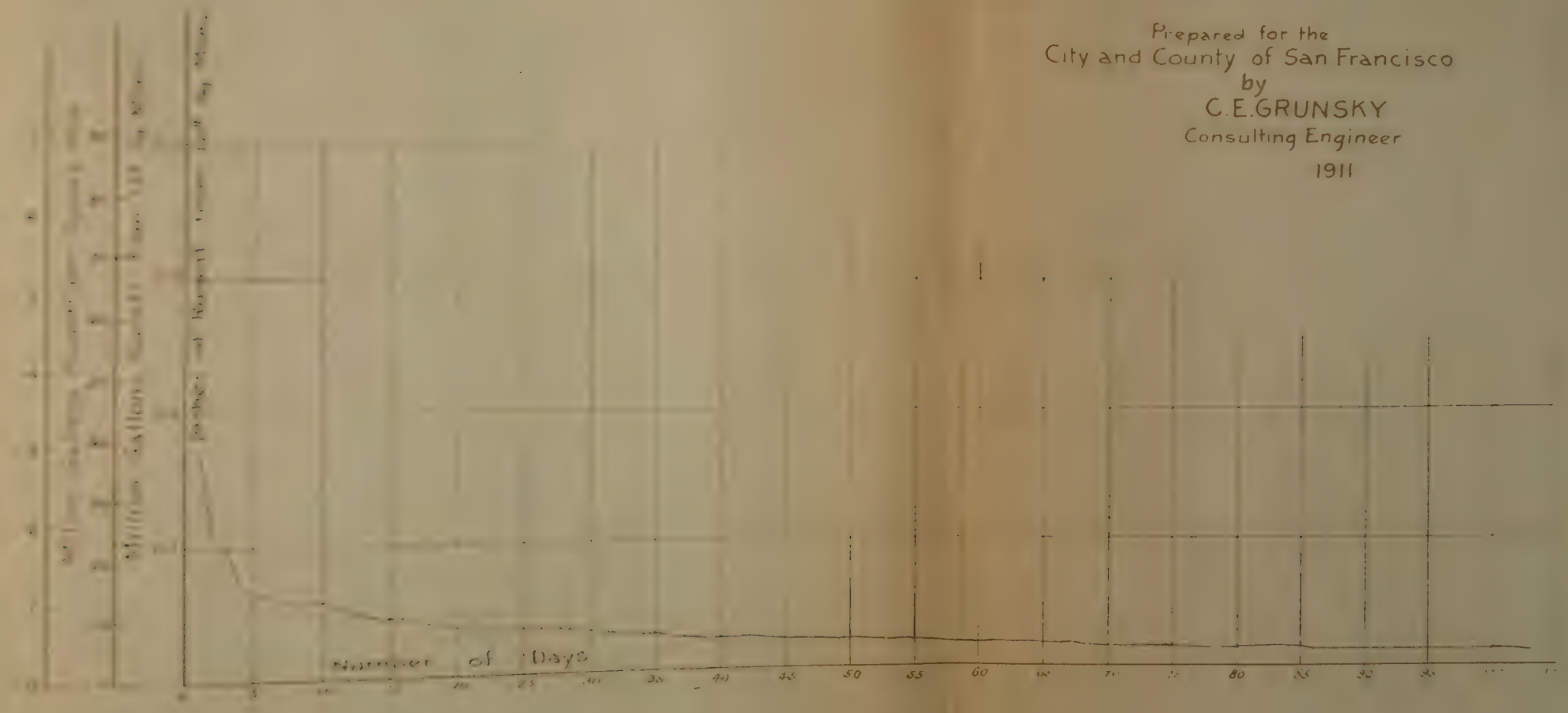


TABLE XXXI

Pilarcitos and San Andres Reservoirs
Watershed 13.8 Sq.Miles.

Runoff during 3 years.

Amount Million Gals. Per Sq.Mile Per day.	Number of days			
	1894-95 Rain 134 % of normal	1896-97 Rain Normal	1897-98 Rain 51% of normal	Average for the selected years
Less than .25	195	183	380	319
More than .25	170	182	85	146
" " .50	145	136	35	105
" " 1.00	82	91	10	64
" " 2.00	37	60	1	29
" " 5.00	15	13	0	9
" " 10.00	3	5		3

It is to be noted that the runoff during the year which was selected as a year with copious rainfall falls below the runoff of the year with normal rain. In the case of the former the rain was better distributed for retention by the soil and evaporation than in the case of the latter. As the selection of the three years was made arbitrarily, based solely upon the amounts of rain this peculiarity was disregarded and the average results for the three seasons were used in making the study of runoff from the ocean slopes, as heretofore explained.

LOWER SACRAMENTO RIVER AS A SOURCE OF WATER FOR SAN FRANCISCO.

By C. E. Grunsky, Consulting Engineer.

(See in this connection Progress Report, Water supply investigation by C. E. Grunsky, City Engineer, Municipal Reports of San Francisco, 1900-01, pages 247-280)

If there were no other source of water available San Francisco could make use of Sacramento River water. The river has an ample flow to more than meet the ultimate requirements of irrigation within its drainage basin.

In its natural condition, before contemination resulting from human activities, the river water was of good quality. This is particularly true of the main stream and of its tributaries at the points where they enter the great California Valley. But now, even under the present conditions, with a drainage basin only sparsely populated the waters are subject to the suspicion of contamination in all the principal feeders of the lower river and the water can no longer safely be used for domestic purposes, without suitable treatment.

This water can not be thought of for San Francisco without filtration and perhaps with additional treatment by some approved process to make reasonably sure that it will be wholesome when delivered to the consumer.

At time runs on the population in the region drained by the river will increase enormously. Not only will the valley with its several million acres of fertile land susceptible of the highest cultivation attract a dense rural population, but great cities will be supported by the surrounding country. And the development will not be confined to the valley alone, but will extend far into the mountains. Where now the people are numbered by hundreds of thousands they will at no very distant day be numbered by the millions.

When that time comes the entire valley will be under irrigation systems. There will be more water used during the summer months than is now flowing in the streams. More than 6,000 second feet will be in the canals in July, August and perhaps even in September. What the natural flow of the streams does not supply will be obtained from storage.

To some extent of course the requirement that portions of the river be kept navigable at all stages, may interfere with the complete diversion of the water from the streams where they enter the great valley, but the extent to which ultimate storage and diversion of water for irrigation and the storage and use of water for power purposes will interfere with navigation interests can not now be foretold. There is no question that as irrigated areas are extended, the ground will be filled up with water and the amount of return waters which reach the river will increase.

The area of irrigable lands in the Sacramento Valley is estimated by Federal authorities to be about 2,000,000 acres. Of this perhaps three-fourths, or about 1,500,000 acres will some day be actually irrigated. On the assumption that in August 5.4 inches of water and in September 3.6 inches over this area would be desirable from the streams, it can readily be estimated that the streams of the Sacramento Valley might in these months be drawn upon for 23,500 second feet and for 15,000 second feet which is from 2 to 3 times the amount which the Sacramento River and its tributaries, under natural conditions, bring into the valley during these months. In case that irrigation should ever be declared paramount to the navigation interests on the Sacramento River- as they are already tacitly conceded to be on the San Joaquin River- practically all the low water flow of the river will be used for irrigation and the deficiency will be supplied, in part at least, out of storage.

As early as 1866 under the auspices and by authority of the State a survey was made by civil engineer, Mr. Bryan, for a west side irrigation canal with its head near Red Bluff. The capacity of this proposed canal which was to be fed by Sacramento River was fixed at 6,571 second feet. This is about one and one half times the low water flow of the river at that point and may serve to give some idea of the magnitude of the canal system that will ultimately be required to serve both sides of the valley.

In the San Joaquin Valley the irrigable area northward from the drainage basin of Kings River is approximately 4,150,000 acres. One half of this area is already commanded by irrigation canals.

Again assuming that at some time three-fourths of the irrigable land will be demanding water and that the amount desired in August and September will be 5.4 and 3.6 inches respectively, then there should be available in the canals a total of 34,000 second feet in August and 16,000 second feet in September.

The combined ordinary low water flow of the rivers descending from the Sierra Nevada from the Consumnes River south to and including the San Joaquin River is about 2,600 second feet in September. This is only about one-tenth of the water which the irrigator according to present ideas would like to have.

To a considerable extent the deficiency can ultimately be supplied out of storage, but in any event there is not likely to be any natural low-water flow left in the lower river. Whatever water in the late summer and fall is there found will be return water.

Conditions as they exist in the great Central Valley of California to-day will be modified as the reclamation of the swamp and overflowed land is extended and as more land is brought under intense cultivation by irrigation. In the Sacramento Valley the area actually irrigated

to-day is less than 4 per cent of the irrigable area in this Valley. The grain grower in this valley has been so successful in the past without irrigation, that the change to improved methods of agriculture and to intense farming has been exceedingly slow. But his eyes are being opened and the time is at hand when the demand for water for the field is becoming general. The construction of irrigation canal systems in the Sacramento Valley may be expected to be much more rapid in the near future than it has been in the past.

It follows from these facts that when irrigation becomes general, there will be a large amount of return water reaching the lower portions of the rivers. How much or what proportion of the low water flow no one can foretell.

The return waters are not the same in quality as the original runoff from the rivers' watersheds. These waters in large part will have saturated the soils and subsoils and will carry away from them more or less mineral and organic matter in solution and suspension.

Predictions relating to the quality of the water that may be available in lower Sacramento River when irrigation becomes general should therefore be made with some reservation.

To illustrate the situation, attention may be called to the fact that about 800,000 acres of lands in Sacramento Valley which are subject to overflow are for the most part yet to be reclaimed. These lands will

All be provided with drain ditches and the rain and seepage waters collecting in these ditches, with all the refuse which they pick up, will be discharged either by gravity flow or by pumping into the river. Much of the swamp and overflow land lies so low that the natural water-table needs lowering for successful cultivation. In such cases the fact that the drain ditches will be carrying much water that has been in the soils and subsoils, is particularly apparent.

When the lands of the valley are irrigated every irrigation system will have coupled with it a drainage system. The rising soil-water instead of being allowed to be drawn to the surface by capillary attraction, and leaving there its burden of alkali, should be carried away in drain channels and in some measure may be used repeatedly for further irrigation until its increasing salt contents render it unfit for further use. Thereupon it should go to the stream. Such return water is not a desirable water for domestic use and when commingling with the natural flow of the rivers does not improve the quality of their waters.

In addition to return waters, however, all the water-borne wastes of a dense population will contribute to a deterioration of the natural stream flow. No matter what precautions may be taken by small establishments or by municipalities in which sewage or other water carried wastes originate, to so treat the sewage or other wastes that offensive and harmful materials will be kept

out of the streams, there will be something left over to go into the watercourse. There will be the effluents from septic tanks or from Imhoff or other tanks, or from sewage filter beds, or the drainage from sewage farms, or perhaps even some crude sewage and much of the waste that originates on the river boats, the house boats and other craft which will always be found upon the river.

No water can be taken for a municipal supply from Sacramento River at or anywhere near Rio Vista which will not have been in part some sewer system.

While it may be granted that such water can be made wholesome, and while it is a well known fact that there are many municipalities which are so situated that they must by force of circumstances be content with water from sources known to be contaminated, this is no reason why a city like San Francisco with a pure mountain water within reach should be compelled to make use of any inferior water. That which is the best from every point of view is what the City wants. No one can make the public quite as content with a contaminated water that has been made good by treatment as with a water admittedly pure at its source.

Not only is this the case but even apart from possible contamination, there will be a material difference between the quality of the water obtainable from the lower reaches of the Sacramento River and such sources as the Tuolumne River.

To make this plain a few of the chemic analyses of waters that have been made will be here referred to without giving all the detail which is to be found elsewhere in this report in tabular form.

TABLE XXXII

Comparison of Waters from various sources.

Source of Sample	Date	Total Solids: parts in 1,000,000	Hardness by Soap
Lake Eleanor,	Sept.30,1903	14.	
Tuolumne River in Hetch-Hetchy Val.	Sept.30,1903	30.	
Tuolumne River in Hetch-Hetchy Val.	Sept.22,1911	40.	
Sacramento River at Red Bluff	Sept. 3,1911	111.5#	64.3
Sacramento River at Rio Vista	Aug. 4,1911	125. #	60.0
Sacramento River at Rio Vista	Sept. 1,1911	110. #	68.6
Central Canal near Willows	Sept. 2,1911	113. #	62.9
Drainage water near Willows	Sept. 3,1911	187.5#	124.
Woodland Canal	Sept. 1,1911	283 #	202.
Woodland Drainage	Sept. 1,1911	285	204.
Gridley Canal	Sept. 5,1911	92.5#	60.
Gridley Drainage	Sept. 5,1911	146.5#	104.5

Solids after filtration.

The samples from Lake Eleanor and from the Tuolumne River were taken at low stages. The sample from Lake Eleanor is believed to be fairly typical of the water which would be obtained from any large reservoir in the upper portion of the watershed of Tuolumne River or its tributaries. It seems reasonably certain that the Tuolumne River at its high stages when most of its water comes

directly from melting deposits of snow would show less amounts of solids than noted for the two samples which were both taken late in the season when the river was low.

From the water analyses by the U.S. Geological Survey in co-operation with the California Department of Engineering, as reported in Water Supply Paper No. 237 of the U. S. Geological Survey, some conclusions can be drawn relating to the varying quality of the water of Tuolumne River at its different stages. The samples of Tuolumne water referred to in this bulleti were all taken near La Grange far below the Hetch-Hetchy valley. They do not fairly represent the water from the high mountain portions of the drainage basin. The following is from the bulletin page 51-

> "The bed rock of the basin is granite, which on the higher elevations is bare and glaciated. Along the middle reaches of the river the soil covering is good, with a heavy growth of pine, fir, cedar and kindred trees. On the lower reaches there is a good covering of brush, which diminishes in the foothills as the stream approaches the San Joaquin Valley. This part of the basin has a light soil covering, with growth of grass which is used for pasturage. In the upper portions of the basin are several glacial lakes, some of the larger offering exceptional advantages for the construction of storage reservoirs."

Seventeen analyses (each of water compose of 10 separate samples) were made of Tuolumne water at La Grange in the first six months of 1906 and 18 in the last six months. These show generally 40 to 60 parts per million of solids in clear water, for the period in which the river carries large volumes of melting snow, while at the river's low stages from 90 to 134 parts per million were found in the samples. These analyses it will be noted show higher solid contents than those that have been made of water from Tuolumne River taken in Hetch-Hetchy Valley and from Lake

Eleanor, and are referred to merely for one purpose, as stated, of showing the larger amount of mineral matter in the water at the low stages of the river than at its high stages.

Some additional information on this subject will be found in Water Supply Paper No. 274, page 128, confirming the above, but showing one result in midwinter with 170 parts per million (Dec. and Jan. 1905-06)

If now the river at La Grange, as shown by these analyses, carries only one-third to one-half as much mineral matter at the spring high stages as at low water stages, a similar relation between the quantity of mineral matter may be inferred for the river in Hetch-Hetchy Valley. It should be remembered too that the water to fill the big reservoirs in the high mountains is the water of the river at its high stages when its quality is at its best.

Although the solids noted for Sacramento River water at Red Bluff and at Rio Vista are well within the limits allowable for potable waters, it will readily be seen from the above exhibit that the purer water obtainable from the Tuolumne is to be preferred.

It is particularly noteworthy too in the above exhibit that of three comparisons that have been made in the Sacramento Valley between canal water and water from drain ditches, two show a marked increase in contents of solids and in hardness, while the third shows practically no change. This result is to be accepted as good evidence that there will be a gradual deterioration of the water flowing in Sacramento River at Rio Vista. The deterioration in chemical composition can not

moreover be offset or eliminated by simple filtration.

In other States, notably in Colorado, there have been some special studies made of the changes which take place in the irrigation waters from the time that they are applied until they reappear in drain ditches. The results of an investigation of this kind, by Dr. William P. Headden, relating to the Colorado Irrigation Waters are published in Bulletin No. 28 of the Agricultural Experiment Station of the Colorado Agricultural College.

In this Bulletin,page 53, Dr. Headden says:

We have considered the Poudre water and seen that it suffers little or no change in character so long as it remains in its mountain course but that its character changes rapidly as it enters the plains. We have seen that in flowing through the ditches for use in direct irrigation it also changes rapidly." And again on page 54-

"The water of the Poudre is taken from the river, used for irrigation and after a time returns. The return waters have been passed through or flowed over the soil x x x Much of the water appearing in the lower part of the river has doubtlessly been used several times.x x x x x x."

On page 70. "In the case of the Poudre waters used by the town of Fort Collins, the total solids contained in the water increases from 8.9 grains per imperial gallon, in the mountain section, to an average of perhaps 10.8 grains as delivered to the town, an increase of three anf one third times the original amount present. This change produced by its flowing through less than eight miles of its course lying within its plains section." X X X

"The influence of the plains section of the stream upon the character of the water is increased by the irrigation of the adjacent lands."

On page 6- "The river water as it is delivered to the town of Fort Collins, for domestic consumption is, from a chemical standpoint, a good water for domestic purposes; but a comparison of it with the river water further up stream shows that it has already suffered a considerable change, due to admixture of seepage which has found its way to the river."

Dr. Headden in a later Bulletin, No. 83, of the same Agricultural Experiment Station, in writing on the same subject says:-

"It is well known, but still more generally accepted as a fact, that the waters of rivers rising in high mountains where there is little

soil, a scanty vegetation and no human beings to pollute them, are comparatively pure, many of them very pure indeed. This is the case with the waters of our mountain streams and is not a fancy arising from notions which we associate with the mountains and their seclusion. The rocky face which their surface so generally presents does not wholly withstand the attack, gentle though it seems, of the falling rain or melting snow. The rocks yield little by little it is true, but the water is never able to enrich itself greatly in mineral matter at their expense. The work done by the waters in a year, a month, or even in a week, when measured in the aggregate is surprisingly large, but no given quantity of this water, a gallon or so, carries more than an infinitesimal part of the product. This water is usually colorless and free from organic matter because we have no accumulation of decaying organic matter such as peat, etc. to contaminate it. Where the surface is covered with soil there is little difference between the soil and the rocks on which the soil rests. I do not know whether the changes which take place in this soil proceed more rapidly than in the rocks proper or not; it is presumable that they do, but they are essentially of the same kind and this is true throughout the mountain region. These waters suffer little change so long as they continue to flow over the rocky beds which they have cut for themselves in the flanks of the mountains, or so long as they move through the soils which are little more than the pulverized rock on which they lie. This, however, is no longer true when they issue from the mountains and enter the plains.

We think of water flowing in a stream as being the same water that it was at its source. In a certain sense it may be, but if we apply this to mean that the water in our streams after they have issued from the mountains is the same in the quantity and character of the salts that it holds in solution as before, we err and are confronted by a series of facts that prove us to be in error. There may be occasions when the pure waters of the mountains are carried further down their course before they suffer changes than under normal conditions, but that they subsequently fall a prey to the general lot is beyond question."

After referring to the character of the salts in solution and chemical changes which take

place after the rivers leave the mountains, Dr. Headden refers to the cause of these changes: "The cause of these

> changes is the entrance of water from the land adjacent to the river course, or return waters."

Although these Colorado studies were made on streams not comparable with the Sacramento in the matter of volume of flow, the principle is the same. The actual amount of change in the quality of the river water must be expected to increase as irrigation is extended.

In the case of San Joaquin River there is already a demand for all of the low water of its tributaries, for irrigation down to the Tuolumne River. What part of the small low water flow of this river which reaches its delta region is return water is not definitely known. That some of it flows out of the subsoils of the irrigated regions of the valley is beyond question. It will suffice to allude to the present low water flow of Dry Creek near Modesto which now discharges some 10 second feet of water into the Tuolumne River at that point, whereas, a few years ago, before there was any irrigation of lands upon its borders, it had no summer flow.

During the low stages of the San Joaquin, as already explained, there will ultimately be no water in its lower reaches, nor in the Old or Middle River branches of this stream, except return waters and of these only so much as may be spared by the irrigator who has need for all even though he has to lift it out of the river channel by pumping.

In View of these facts no consideration should be given to either the lower Sacramento River or the lower San Joaquin River as available sources of water for San Francisco so long as high mountain sources are available.

WATER ANALYSES.

Some information relating to the quality of the water to be obtained in the drainage basins of the Sacramento and San Joaquin Rivers has already been given. For analyses of water from various streams in California, giving the most important facts, reference may be had to Water Supply Paper No. 237 of the United States Geological Survey entitled "The quality of the surface waters of California."

Attention may also be drawn to the fact that in the years 1900 and 1901 under the direction of the writer, who was at that time City Engineer of San Francisco, numerous chemical analyses and bateriological examinations were made of the waters which were being collected and delivered by the Spring Valley Water Company. The results of these analyses and examinations were published in the Municipal reports of 1900-1901, Appendix page 353, etc.

The examination of the Spring Valley Water was continuedby the Board of Health of San Francisco and numerous analyses have since been made.

The quality of the water obtainable from Tuolumne River may be judged from the analyses made by the city chemist, Mr. Frank T. Green, in 1903.

Two samples of water were taken in sterilized large bottles by a chemist, Mr. J.H.Gray, acting under the writer's direction, the one from Lake Eleanor on September 30, 1903, the other on the same day from Tuolumne River in Hetch-Hetchy Valley. The river was at that time at a low stage. The samples from the lake, it was thought, might be regarded as typical of the water that would be held in the enlarged Eleanor reservoir and in the proposed Hetch-Hetchy reservoir. The results of the analysis were favorable, as will be seen from the following, submitted by Mr. Green under date of November 7, 1903.

	Lake Eleanor Parts in 1,000,000	Tuolumne River Parts in 1,000,000
Total solids,.....	14.	30.
Loss on ignition,.....	4.	4.
Fixed residue,.....	10.	26.
Chlorine as chlorides,.....	1.98	3.57
Oxygen consumed,.....	1.32	.7
Nitrogen as albuminoid ammonia,....	.06	.05
In first 50 cu.cm.....	55%	53%
In second 50 cu.cm.....	37%	26%
In third 50 cu.cm.....	8%	13%
In fourth 50 cu.cm.....		8%
Nitrogen as free ammonia.....	.04	.084
In first 50 cu.cm.....	50%	77%
In second 50 cu.cm.....	34%	18%
In third 50 cu.cm.....	16%	5%
Nitrogen as nitrites,.....	.0003	.0004
Nitrogen as nitrates,.....	.024	.012

Quantitative (Acids and Bases).

Parts in 1,000,000 #

	Lake Eleanor	Tuolumne River
Total solids,.....	14.	30.
Fixed residue,.....	10.	23.
Silica, SiO_2	3.07	5.67
Magnesia, MgO,.....	0.28	0.60
Iron and alumina, Fe_2O_3 Al_2O_3	0.17	0.57
Lime, CaO,.....	1.27	3.77
Sulphur trioxide, SO_3.....	1.01	1.31
Sodium chloride, NaCl,.....	3.87	5.90
Carbon dioxide and undetermined,...	0.93	8.18

Calculated into Salts.

Parts in 1,000,000

Calcium sulphate, $CaSO_4$.....	1.717	2.22
Calcium carbonate, $CaCO_3$.....	1.014	5.09
Magnesium carbonate, $MgCO_3$.....	0.588	1.26
Sodium chloride, NaCl.....	3.270	5.90
Silica, SiO_2.....	3.070	5.67
Iron and alumina, Fe_2O_3, Al_2O_3.....	0.170	0.57
Undetermined,.....	0.171	5.29

It is reasonably certain that Tuolumne River at its high stages would show still less of total solids in solution.

The following analysis of a sample of Lake Tahoe water, taken on October 16, 1900, was made by Mr. J. H. Gray, acting under the writer's direction. It is noted for comparison and to show the general excellency of the waters originating in the high mountains of the Sierra Nevada.

One Liter, the quantity used for each estimation, except in case of sulphates, than 500 cu.cm.

Lake Tahoe Water.

Parts in 1,000,000

Total solids,.....	65.
Loss on ignition,.....	15.
Fixed residue,.....	50.
Chlorine,.....	1.42
Nitrogen as nitrites,.....	None
Nitrogen as nitrates,.....	Trace
Nitrogen as free ammonia,.....	0.006
Nitrogen as albuminoid ammonia,.....	0.034
In first 50 cu.cm.....	71%
In second 50 cu.cm.....	23%
In third 50 cu.cm.....	6%
Oxygen consumed,.....	0.10
Bacteria at 100 yds.off shore per cu.centimeter	1
Bacteria at 200 yds.off shore per cu.centimeter,	0
Bacteria at 300 yds.off shore per cu.centimeter,	0
Bacteria at 500 yds.off shore per cu.centimeter,	0

The water for the bacteriological examination was taken at a later date. It was plated immediately upon being taken and the results noted are considered reliable.

A sample of water for bacteriological examination from near the lake outlet was taken at the same time that the samples for chemical analysis were taken showed a few bacteria(60 cubic centimeter are recorded, page 344, AppendixMunicipal Reports of San Francisco, 1900-1901), but it is noted (on page 379) that the determination of the number of bacteria should be ignored because immediately after the samples were taken a light flaky substance was noticed in the water, and because a delay in transportation occurred, making the time two days before the samples reached the laboratory.

In the current year, 1911, a number of samples of water have been analyzed for the City Engineer and still others were collected and analyzed at the request of the writer by Prof. Edmund O'Neill of the University of California. The results of these latest analyses are presented in the following table:

TABLE XXXIII

Water from various sources-Analyzed by Prof. Edmund O'Neill.

	Parts in 1,000,000			Year 1911		
	Tuolumne River H.H.Val.	Eel Riv. S. Fork at Cape Horn	Eel Riv. below Potter Val.	Sacto Riv. at Red Bluff	Sacto Riv. at Sacramento	Sacto Riv. at Rio Vista
	(1)	(2)	(3)	(4)	(5)	(6)
Date	Sept. 28	Aug. 20	Aug. 20	Sept. 3	Sep. 18	Aug. 4
Total solids unfiltered,				130.5	142.	189.
Total solids clear water	40.	163.	189	111.5	104.	135.
Soluble, after Evaporation	18.15	63.5	76.	35.	43.	49.
Insoluble " "	3.	80.	105	67.5	42.	60
Volatile at low heat	18.5	19.5	8.	9.0	19	16
Chlorine	Trace	Trace	Trace	0.5	Trace	10.
Nitrites	Trace	0.0	Trace	0.0	Trace	0.006
Nitrates	Trace	Trace	Trace	0.0	Trace	0.250
Free Ammonia	Strong) Trace)	0.028	-----	0.046	0.024	0.044
Albuminoid Ammonia	0.01	0.038	-----	0.036	0.038	0.090
Required Oxygen	2.22	2.74	0.66	0.30	1.05	4.25
Dissolved Oxygen				7.60	7.82	8.32
Alkalinity, sodium Carbonate	10.	22.	16.	15.9	10.	11.9
Hardness Titration				40.	59.	53.7
" by Soap				64.3	62.9	60.

(1), (2) and (3) collected by City Engineer, Mr. Marsden Manson
(4) to (17) collected by Prof. Edmund O'Neill at the request of writer.

(2) From a point 100 yards above the diverting tunnel of the Snow Mountain Power Company.

(3) Below Potter Valley; just above Cold Creek.

TABLE XXXIII (Continued)

Parts in 1,000,000 — Year 1911.

	Sacramento River at Rio Vista	Feather Riv. at Oroville	Yuba Riv. at Daguerre	Amer. Riv. at Fair Oaks	Cent. Irri. Canal No. of Hamilton	Cent. Irri. System Drain
	(7)	(8)	(9)	(10)	(11)	(12)
Date	Sept. 1	Sept. 5	Sept. 4	Sept. 6	Sep. 2	Sept. 3
Total solids unfiltered	141.	101.	91.	82.	131.	254.
Total solids clear water	110.	90.	80.	78.	113	187.5
Soluble after Evaporation	40.	30	23.5	20.	42.5	60.
Insoluble " "	71.	59.5	55.	56.5	62.	109.5
Volatile at low heat	8.5	0.5	1.5	1.5	8.5	18.
Chlorine	Trace	0.5	0.5	0.5	6.0	12.
Nitrites	0.002	0.0	0.0	0.003	0.0	0.002
Nitrates	Trace	0.0	0.0	0.05	0.0	0.200
Free ammonia	Trace	Trace	Trace	Trace	0.02	0.020
Albuminoid Ammonia	0.014	0.016	0.021	0.018	Trace	0.015
Required Oxygen	1.14	0.67	0.56	0.73	0.25	0.84
Dissolved oxygen	5.30	8.07	7.35	8.00	6.90	5.83
Alkalinity, Sodium Carbonate	15.9	13.3	13.3	13.3	21.2	20.
Hardness Titration	58.5	53.7	43.7	27.5	50.	76.
" by Soap	68.6	68.6	57.1	45.7	63.9	124.

Parts in 1,000,000 — Year 1911.

	Woodland Irri. Canal at Cache Creek	Woodland Irri. Sys Drain	Butte Co. Canal at Headgate	Butte Co. Irri. Sys Drain	Willows Hill Resv. near Folsom
	(13)	(14)	(15)	(16)	(17)
Date	Sept. 1	Sept. 1	Sept. 5	Sept. 5	Sept. 12
Total solids unfiltered	303.	315.	104.5	170.	59.
Total solids clear water	283.	285	92.5	146.5	57.
Soluble after Evaporation	135.5	128	31.	30.5	21.
Insoluble " "	110.5	117.	62.	114.	23.5
Volatile at low heat	30.	40.	0.0	8.	8.
Chlorine	44.	38.	<0.5	<0.5	Trace
Nitrites	0.002	0.008	0.0	0.004	0.0
Nitrates	0.035	0.035	Trace	Trace	0.0
Free Ammonia	0.012	0.088	Trace	0.048	0.048
Albuminoid Ammonia	0.018	0.060	0.016	0.112	0.046
Required Oxygen	1.14	1.22	0.90	2.16	1.67
Dissolved Oxygen	6.52	6.30	8.20	7.54	7.82
Alkalinity, Sodium Carbonate	37.8	29.2	11.9	21.2	8.
Hardness Titration	135.	153.5	52.5	90.	29.
" by Soap	202.	204.	60.0	104.8	32.5

(12) Seepage water on Sacramento River S.E. of Willows.
(13) At headgate, 8 miles west of Woodland.
(14) About one mile south of Woodland Railway Station.
(15) About 10 miles N.E. of Gridley.
(16) Seepage water from Slough ½ mile E.of S.P.Ry Station at Gridley

CHAPTER VI.

IRRIGATION AND STREAM FLOW IN SACRAMENTO VALLEY AND NORTHERN PORTION OF SAN JOAQUIN VALLEY.

IRRIGATION AND STREAM FLOW

IN SACRAMENTO VALLEY AND NORTHERN PORTION OF SAN JOAQUIN VALLEY.

No attempt will be made to treat the subject of irrigation in the Sacramento and parts of the San Joaquin Valley exhaustively. It is proposed to give in briefest outline some of the salient facts, however, that may prove of service in any study or discussion of the availability of the lower portions of either the Sacramento River or the San Joaquin River as sources of water to supply the needs of San Francisco.

The San Joaquin and its tributaries are only brought into consideration as far south as where the main river breaks out of the foothills of the Sierra Nevada into the San Joaquin Valley, because the rivers to the south do not contribute directly to its low water flow. The only contribution which might be expected is drainage water from the region westerly from Fresno and this only comes into consideration in a broad way as an undesirable feature but without any attempt to analyze or predict its amount.

A map, Fig. 28, has been prepared to show in an approximate way the larger irrigation canal systems and the irrigation districts in the Sacramento Valley and in the northern portions of the San Joaquin

Valley. This will help better than it can be done in words to show how large a part of the valley lands are not yet under ditch. It is to be noted, however, that in some cases but little of the shaded area(representing land under ditch and land in irrigation districts) has been actually irrigated.

In such extreme cases as those of the South San Joaquin and Oakdale districts, only 3000 to 4000 acres have received water out of a total area in both districts of 135,000 acres. But the map makes clear that the value of irrigation is being recognized and that an extension of irrigation works to other parts of the valley in the near future must be assumed.

The facts here presented have been brought together mainly by Mr. A. E. Chandler, formerly with the U. S. Reclamation Service, and are based upon recent investigations by the Census Bureau of the U. S. Department of Commerce and Labor, Irrigation Investigations of the Department of Agriculture, and the U. S. Geological Survey.

THE SUMMER FLOW OF THE SACRAMENTO AND SAN JOAQUIN RIVERS AS AN IRRIGATION SUPPLY.

THE SACRAMENTO RIVER AND ITS TRIBUTARIES.

The total arable and irrigable area in the floor of the Sacramento Valley is about 2,500,000 acres. As from one-fifth to two-fifths of this area is subject to overflow, the acreage adapted to irrigation is generally accepted as about 2,000,000 acres. According to data recently assembled by Irrigation Investigations of the Department of Agriculture, there are in the Sacramento Valley 395,806 acres under ditches from streams and 65,808 acres were irrigated thereby in 1909. In addition thereto 12,860 acres were irrigated by water from wells in 1909, making a total of 78,668 acres irrigated- less than four per cent of the area adapted to irrigation.

The above totals refer to irrigation on the floor of the valley only. There are many thousands of acres irrigated in the mountain valleys and foothills by the Sacramento and its tributaries. The gaging stations herein referred to are below the foothill diversions and the records of stream flow indicate the water available for irrigation of the valley floor.

If no ditches had been constructed in the Valley it might be feasible to plan a system whereby the many streams might be so diverted that the entire 2,000,000 acres could be irrigated. Owing to the many existing ditches, however, such a plan is not practicable and no analysis will be given herein of the combined flow of the Sacramento and its tributaries, but each stream will be treated as a unit.

There are a great many creeks on both sides of the valley which carry considerable water in the early irrigation season, but are dry by July first. Many ditches have been constructed to utilize the flow of such creeks and the irrigated acreage thereunder is included in the above totals. Storage projects have been proposed for the storm waters of a number of these creeks, especially Thoms and Elder Creeks, in Tehama County. As such projects will add but little if anything to the summer flow of the Sacramento they will be referred to very briefly while the streams having a perennial flow will be more fully considered. They are Stony, Cache and Putah Creeks on the west side, and Antelope, Mill and Deer Creeks and Feather, Yuba, Bear and American Rivers on the east side of the Valley.

STONY CREEK

The United States Geological Survey has maintained a gaging station on Stony Creek near Fruto for the period 1901-10. The mean monthly discharge is shown in Table XXXV. The average mean for the ten year

period for June was 172 second feet, for July 36 second feet, for August 12 second feet, and for September 15 second feet. It is evident, therefore, that without storage the stream is of little value for irrigation.

The two private canals which formerly diverted the waters of Stony Creek have been purchased by the United States and are now the main canals of the Orland Project of the United States Reclamation Service. The project comprises 14,000 acres in the vicinity of Orland. The dam for a reservoir of 45,000 acre feet capacity situated on Little Stony Creek was completed in September 1910. It is believed that this storage will furnish sufficient water for the project although the Service plans to allow a depth of irrigation of from 3 to 3½ feet on account of the large amount of gravelly soil within the project.

The landowners in the vicinity of the project have petitioned the Secretary of the Interior to construct a second reservoir at Stony Gorge of about 100,000 acre feet capacity and extend the project to cover an additional area of 36,000 acres, but favorable action has not as yet been taken.

On November 30, 1910, the Warmouth Kerling Company filed upon the flood waters of Thoms Creek (the next creek north of Stony) to the extent of 100,000 inches with the intention of diverting such water into a reservoir to be constructed on the North Fork of Stony Creek near Newville

and using the stored water for irrigation in the Sacramento Valley to the north and south of Stony Creek. The undertaking has not yet been financed.

Two other reservoir sites- The Briscoe site of 14,385 acre feet capacity and the Mill site of 43,735 acre feet capacity- were surveyed by the Geological Survey in 1900. None of the above mentioned reservoirs will be constructed except to irrigate sections of the valley north and south of Stony Creek. Their construction, therefore, will not increase the summer flow through the Stony into the Sacramento River. At the present time all the water that is allowed to pass the Orland Project in the early irrigation season is diverted by the Central Canal which crosses the bed of Stony Creek near its mouth by means of a movable dam.

CACHE CREEK.

The Geological Survey has maintained a gaging station in Cache Creek at the outlet of Clear Lake for the period 1901-1910 and at Yolo for the period 1903-1910. The mean monthly discharge is shown in Tables XXXVI and XXXVII. Yolo is below the headgates of the principal existing canals and the mean monthly discharge at Yolo for the summer of 1903, 1908 and 1910 was as follows:

	1903	1908	1910
July	63	4.48	0.58
August	8	0.03	0.00
September	0	0.00	0.00

Litigation over water rights for Cache Creek ditches began in the sixties and continued until 1903 when the Yolo County Consolidated Water Company purchased the three ditches which still existed. It is now in practical control of the irrigation situation about Cache Creek. The summer flow is so low, however, that although there are 30,000 acres under ditches, not more than 10,000 acres have been irrigated and generally less than 7,000 have been served.

As shown by Table XXXVI Clear Lake acts as a natural regulator of the stream. A great number of engineering reports have been made upon the possibilities of artificial storage in the lake and its annual output for power and irrigation purposes has been variously estimated from 200,000 to 500,000 acre feet.

In 1900 the Geological Survey reported upon Little Indian Valley reservoir site on the North Fork of Cache Creek with a capacity of 76,500 acre feet and an annual yield of 50,000 acre feet.

The use of these sites has been considered for over ten years, but no definite steps towards construction have been taken. As there are over 300,000 acres in Yolo County alone which could be covered by ditches from Cache Creek, the demand for water will always be far

in excess of the supply even after the maximum development of storage possibilities.

PUTAH CREEK.

The Geological Survey has maintained a gaging station on Putah Creek near Winters for the period 1904-1910. The mean monthly discharge is shown in Table XXXVIII. The average mean for the seven year period for June was 88 second feet, for July 26 second feet, for August 11 second feet and for September 10 second feet. The summer flow is entirely diverted by small private ditches which irrigated 688 acres in 1909 and which cover 1710 acres. Without storage there can be no material development in irrigation.

The Reclamation Service has surveyed two reservoir sites in the Putah Creek Basin- the Guenoc site with a capacity of 188,000 acre feet and a probable annual yield of 80,000 acre feet, and the Monticello site with a capacity and probable annual yield of 130,000 acre feet. As there are upwards of 150,000 acres which could be covered by canals diverting to the southward only Putah Creek offers excellent prospects for a storage irrigation project, but no concerted effort has been made in this direction. If the reservoirs are ever constructed their regulation will be designed to meet the demands of the irrigated territory and there will be no excess summer flow.

Putah Creek can therefore not be considered as a source of summer flow for the Sacramento River.

ANTELOPE AND MILL CREEKS.

The Geological Survey established a station on Mill Creek on September 23, 1909, but as no gage Height record has been kept no tables of discharge are available, The Survey, however, made a number of measurements through the summer of 1910 which are of importance in connection with low water flow as 1910 was a very dry year. The mean of six measurements taken in July 1910 was 155 second feet, of two measurements in August 1910, 126 second feet and of two measurements in September 1910, 124 second feet.

The low water measurement taken on Antelope Creek on September 17, 1910, showed a discharge of 56 second feet.

Low water measurements taken in 1905 showed a discharge for Mill Creek on September 1st of 132 second feet and for Antelope Creek a discharge of 53 second feet on August 13th and 45 second feet on August 31st. All measurements mentioned above were taken above all diversions.

In 1909, 2,300 acres were irrigated by ditches from Mill Creek and 932 by ditches from Antelope Creek. The Los Molinos Land Company's project embraces about 12,000 acres, 11,000 to be irrigated by ditches from Mill Creek and 1,000 by ditches from Antelope Creek. Only

2,000 acres of the project were irrigated in 1909. Its development and settlement are now being pushed however, and the entire project will be irrigated within the next few years.

In its sales of land the Company fixes the duty of water at the equivalent of one second foot to 230 acres. It has not measured the water to consumers so that no attempt has been made to secure this high duty. It is probable that the entire flow of the two creeks will not be more than sufficient to meet the needs of the developed project and other private projects having rights which have not been defined. If after development and settlement of conflicting claims, there remains a surplus of water, the Company plans to extend its project so that the entire available flow may be utilized.

There are no known storage sites on the Creeks.

DEER CREEK.

Deer Creek when measured by the Geological Survey above diversions on August 12, 1904, had a discharge of 127 second feet, and 83 second feet on September 1, 1905. There are 4,980 acres under existing ditches and they are said to divert the entire summer flow during the drier years.

No storage sites have been reported for the creek's basin. There are thousands of acres of excellent land which could be covered by ditches from the creek if the summer flow were greater.

FEATHER RIVER.

The Geological Survey has maintained a gaging station on the Feather River at Oroville for the period 1902-1910. The mean monthly discharge is shown in Table XXXIX. The average mean for the nine year period for July was 3,037 second feet, for August 1,975 second feet and for September 1,577 second feet.

The Feather River basin is especially favored with reservoir sites. The following table is taken from page 96 of the Fifth Annual Report of the U. S. Reclamation Service.

Capacity of reservoirs surveyed in Feather River Basin.

Name of Reservoir	Description	Capacity of reservoir basin as surveyed	Probable amount available annually from watershed.
		Acre Feet	Acre Feet
Big Meadows	North Fork, Feather River	780,384	780,380
Indian Valley,	Greatest depth of water 110 feet	688,000	500,000
Concow,	North Fork, Feather River	10,012	10,012
Butte	Do	107,000	107,000
American Valley	Do	86,055	86,055
Spanish Ranch Valley	Do	8,469	8,469
Buck Valley	Do	37,843	37,843
Grizzly Valley,	Middle Fork, Feather River	61,820	20,000
Mohawk Valley,	Do	12,626	12,626
Total		1,792,209	1,562,385

The largest of these sites, the Big Meadows, is now being developed by the Great Western Power Company. The dams will be completed in the spring of 1913 and are of sufficient height to give the reservoir a capacity of 1,150,000 acre feet. It is the plan of the company to so regulate this reservoir that a continuous flow of 2,650 second feet will be maintained at the Big Bend on the North Fork. The Company may also utilize the Butte Valley site- capacity 150,000 acre feet,- but no definite plans have been outlined.

The mean monthly flow for July, August and September, 1906 to 1910, for the North Fork at Big Bend and the Feather at Oroville is as follows:

Second Feet

Year	July		August		September	
	North Fork	Feather	North Fork	Feather	North Fork	Feather
1906	2,980	5,240	1,540	2,490	1,310	1,970
1907	2,700	6,000	1,720	2,650	1,470	1,900
1908	1,590	2,320	1,010	1,510	987	1,250
1909	1,820	3,270	1,210	1,800	1,200	1,820
1910	1,161	1,600	974	1,350	997	1,170

The difference between the flow at the two stations was least in 1910 when it was 439 for July, 376 for August and 173 for September. As 1910 was a very dry year a continuous flow of 2,650 second feet in the North Fork at Big Bend should mean a flow in excess of 3,000 second feet during July and August and in excess of 2,800 second feet in September in the Feather at

Oroville.

The only existing diversion from the Feather below Oroville worthy of coment is the Butte County Canal. This system covers about 80,000 acres and irrigated about 20,000 in 1909.

The Feather River Canal Company has started the construction of a canal, to divert the waters of the Feather to a point two miles below Oroville, which if completed must remain the high line canal on the west side of the Feather. The project has not yet been adequately financed but construction work is in progress. When completed this system and the Butte County Canal will cover about 200,000 acres which include practically all the irrigable land south of the Feather River Canal Company's proposed Canal line and between the Feather and Sacramento Rivers.

Owing to a proposed Yuba River project (the Hotle project) to irrigate 70,000 acres lying north of the Yuba and east of the Feather, it is not probable that any large diversion will be made from the east side of the Feather. It is doubtful, therefore, whether the area to be irrigated by the Feather in the Sacramento Valley will exceed 200,000 acres. On a basis of 1 second foot to 160 acres, 200,000 acres would require 1,250 second feet, and, on a liberal basis of 1 second foot to 100 acres, would require 2,000 second feet.

It is evident, therefore, that the storage proposed by the Great Western Power Company will provide a surplus summer flow of several hundred second feet in the

Feather River even after the full irrigation demand has been satisfied.

YUBA RIVER.

The Geological Survey has maintained a gaging station on the Yuba River near Smartsville for the period 1903-1910. The mean monthly discharge is shown in Table XL. The average mean for the eight year period for August was 541 second feet and for September 464 second feet. The means for August 1908 and 1910 were 350 and 328 respectively, and for September 1908 and 1910 were 329 and 383 respectively.

About 2,000 acres were irrigated in 1909 by ditches from the Yuba which cover about 3,500 acres. The "Hotle project" referred to above contemplates the construction of a high line canal to irrigate 70,000 acres. Some work is being done on the canal at the present time. As the system is being designed on a duty basis of 1 second foot to 160 acres, the entire area will require 437 second feet without any allowance for seepage losses. As shown above this demand would be in excess of the flow for dry years like 1908 and 1910. When the rights of the existing ditches are considered the minimum draft on the river would be in excess of 460 second feet.

The only reservoir site reported in the lower Yuba basin is Oregon House Valley which could be reached by a feed canal from the North Fork of Yuba River. It is reported to have a capacity of 90,823 acre feet. It is not likely that this reservoir site will be utilized except for the irrigation of land lying between the Yuba and the Bear and

no such project has been proposed.

Present plans for irrigation development will therefore utilize the entire flow of the Yuba during August and September in the drier years.

BEAR RIVER.

The Geological Survey has maintained a gaging station on the Bear River at Van Trent for the period 1905-1910. The mean monthly discharge is shown in Table XLI. The average mean for the six year period for July was 58 second feet, for August 32 second feet and for September 33 second feet. On the basis of 1 second foot to 160 acres the mean July flow would irrigate 9280 acres and the August and September flow 5,120 acres.

During 1909, 270 acres were irrigated by ditches from Bear River. No recent notices of appropriation of the waters of Bear River have been filed, and there are at present no plans for new diversions from the stream. The low summer flow has no attraction for the promoter of irrigation projects and the stream will undoubtedly be left for individual or small company ditches. There are large areas of land on both sides of the river which require irrigation.

No reservoir sites have been reported in the lower Yuba basin.

In speaking of reservoir sites in connection with Yuba River and Bear River, the expression lower river basin has been used as a number of sites on the upper tributaries of each river are at present utilized by the Pacific

Gas and Electric Company for the irrigation of about 14,000 acres in the higher foothill region. Any new storage by this company will be utilized on the higher land and will not be available for use on the valley floor.

AMERICAN RIVER.

The Geological Survey has maintained a gaging station on the American River at Fair Oaks for the period 1905-1910. The mean monthly discharge is shown in Table XLII. The average mean for the six year period for August was 231 second feet and for September 330 second feet. The mean monthly flow for August in 1905, 1908 and 1910 was 325, 200 and 213 second feet respectively, and the mean monthly flow for September for the same years was 126, 123 and 201 respectively.

On March 31, 1910 the Natomas Consolidated of California filed a notice of appropriation for 40,000 inches (1,000 second feet) of the waters of the American River to be used in irrigation in Sacramento, San Joaquin and Sutter Counties. As this company has large property interests, it is very probable that the project will be constructed. If the completed canal diverts one-half the appropriation, there will generally be a deficiency of water in August and September.

The only reservoir site reported on the American River is the Greenwood site with a capacity of 65,952 second feet. As far as it is known no power company intends to utilize this site so that if ever developed the work will be done in the interest of irrigation.

SACRAMENTO RIVER.

The Geological Survey has maintained a gaging station upon the Sacramento River near Red Bluff for the period 1896-1910. The mean monthly discharge is shown in Table XXXIV. The lowest average mean monthly discharge for the full period was 5,023 for September and the lowest mean monthly discharge was 3,805 for August 1900.

At the present time but a small part of the natural flow is available for irrigation on account of the alleged interference with navigation. The following paragraphs are taken from page 35 of the report of the Army Engineers "On The Control of Floods in the River System of the Sacramento Valley and the Adjacent San Joaquin Valley, California," and contain the recommendation of Mr. Wadsworth, Engineer in charge of field work.

"The subject of the maintenance of good navigable depths at low-water stages is intimately connected with the diversion of water from the river and its tributaries for irrigation purposes, and is one likely to require careful attention in the near future. Water for irrigation purposes stored in reservoirs during the rainy season is no drain on the navigability of the river and may even be an aid in reducing flood heights, but water diverted from the river at low stages, reducing the flow by the amount of the diversion, is a direct detriment."

"The extensive irrigation works now in progress of construction in Glenn and Colusa Counties will require a much larger quantity of water than has heretofore been used. Other projects which are now under consideration and those which are likely to come up will create a demand which, if granted, will seriously affect the navigable depths, particularly above Colusa. The probable effect of the diversion at low-water stage of 1,000 second-feet of water above the mouth of Chico Creek, as computed by me, will be to decrease present depths, between that point and Colusa, from 0.3 foot to 1.5 feet, depending upon the characteristics of the section. The decrease in depth will be least at points

where existing depths are least, but these points are now the critical ones, and a decrease of even 0.3 foot would be a serious matter and would require the construction of contraction works where, for the diversion, they would not be necessary. Therefore, the storage of water on the Sacramento or its tributaries above Red Bluff, either by companies diverting water for irrigation purposes, or otherwise, so that the low-water flow may be increased, should be made a condition precedent to further diversion."

The "extensive irrigation works" in Glenn and Colusa Counties referred to above are those of the Sacramento Valley Irrigation Company which purchased the old Canal from the Central Canal and Irrigation Company in 1909. The latter company in 1906 obtained permission from Congress to divert for irrigation 900 second feet provided said diversion did not interfere with navigation. The present company is pushing the construction of both the irrigation and drainage system and expects to irrigate between 150,000 and 200,000 acres. In 1909 there were only 3,500 acres irrigated. The contracts of the company allow an annual irrigation depth of 18 inches. As stated above, it diverts the surplus waters of Stony Creek in the early irrigation season.

On March 23, 1911 a notice of water appropriation was filed for 125 second feet of the waters of the Sacramento to be pumped to lands in southern Tehama County. If this project is constructed the diversion will exceed the 1,000 second feet limit suggested in the above quotation.

There are a number of reservoir sites on the tributaries of the Sacramento above Red Bluff as shown by the following table taken from page 95 of the Fifth Annual Report of the U. S. Reclamation Service.

Name of Reservoir	Description	Capacity of Reservoir Basin as Surveyed	Probable Amount Available Annually from Watershed
Iron Canyon	150-ft.rubble concrete dam with wasteway	226,900	236,900
Jess Valley	60-ft.loose rock-fill dam with wasteway	324,560	
West Valley	70-ft.loose rock-fill dam with wasteway	94,579	
Warm Spring Valley	do	559,015	
Big Valley	100-ft.concrete overflow dam	3,196,188	1,00,400
Round Valley	70-ft.loose rock-fill dam with wasteway	184,732	
		4,485,974	

Note. a. Big Valley reservoir site is below Jesse Valley, West Valley, Warm Spring Valley and Round Valley reservoir sites.
b. This estimate includes discharge from Goose Lake drainage.

Residents of Tehama County have been interested in the Iron Canyon reservoir site for a number of years. It was hoped that the Reclamation Service would construct the dam for the irrigation of land on the west side of the river, but all investigations of the project were suspended in the summer of 1909. As all the land within the project is in private ownership it is not believed that the Government will undertake its construction. Notices of appropriation of the waters of the Sacramento at the dam site have been periodically filed and those interested in the development of the project now hope to secure private capital to construct it as a power and irrigation proposition.

The Fifth Annual Report of the United States Reclamation Service (page 96) gives the area of the valley land in the west side of the Sacramento between Red Bluff and the line of the Central Canal which could be irrigated by Iron Canyon reservoir and Stony Creek reservoirs as 352,000 acres.

A number of engineers have recommended the construction of the reservoirs on the upper Sacramento and tributaries as a means of flood protection. The idea has been considered by the Army Engineers with the following conclusion:

> "While favoring the use of reservoirs as far as possible, and considering that one of the advantages of the project herein proposed is that it lends itself to future storage possibilities, the commission believes that it is not economical to construct reservoirs for flood control, but that such construction should be deferred until these reservoirs prove desirable for power and irrigation purposes." Extract from Reports on the Control of Floods in the River Systems of the Sacramento Valley and the adjacent San Joaquin Valley, California.

Excepting the Feather River the summer flow of all the tributaries to the Sacramento below Red Bluff is either now diverted or appropriated for projects now planned. It is probable that the summer flow of the Feather on account of its regulation by power companies will be several hundred second feet in excess of the irrigation demand. As stated above, the recommendation has been made to the War Department that the diversion from the Sacramento above Chico Creek be restricted to 1,000 second feet. As so little has thus far been diverted from the east side streams the Army Engineers have not considered the effect of diversions from them on navigation on the Sacramento River. The question of return flow from the irrigated sections will necessarily be an important issue in such

consideration. The return waters may be sufficient to give sufficient depth for navigation purposes but future measurements only can answer the query.

SAN JOAQUIN RIVER AND ITS TRIBUTARIES.

Of the 7,325,000 acres of land in the San Joaquin Valley, 3,200,000 lie in that portion here under consideration, that is entirely to the northward of the Kings River drainage basin. It is true that at high stages some water from Kings River ordinarily flows into the Fresno Slough region and thence into the San Joaquin but at low stages the entire flow of Kings River is in the irrigation canals and is applied to land. Consequently this river and all streams to the southward of the low flat ridge which impounds Tulare Lake need not be taken into account when discussion the low water flow of the lower San Joaquin River.

The total irrigable area in the floor of that portion of the San Joaquin Valley here under consideration is about 2,450,000 acres. According to data recently assembled by Irrigation Investigations of the United States Department of Agriculture, there are, in this part of the San Joaquin Valley, 1,224,700 acres under irrigation ditches and 302,350 acres were irrigated thereby in 1909. In addition thereto 11,025 acres were irrigated by water from wells in 1909, making a total of 313,375 acres irrigated- about thirteen per cent of the total irrigable acreage.

For the reasons given in the discussion of possibilities in the Sacramento Valley, the San Joaquin and each of its important tributaries will be treated herein as units rather than attempting to combine the entire flow. The streams to be discussed are the Consumnes, Mokelumne, Calaveras, Stanislaus, Merced, Fresno and San Joaquin Rivers and Chowchilla Creek.

CONSUMNES RIVER.

The Geological Survey has maintained a gaging station on the Consumnes River at Michigan Bar for the period October, 1907-1910. The mean monthly discharge is shown in Table XLIII. The average mean for the three year period for June was 161 second feet, for July 26 second feet, for August 4.4 second feet and for September 6.8 second feet.

It is evident, therefore, that the stream without storage is of little value for irrigation purposes. The Volcano reservoir site with a reported capacity of 44,000 acre feet is situated on the headwaters of a tributary of the Consumnes. It is planned, however, to utilize what storage can be obtained in this site for diversion into the American River watershed so that it is probable that the site will never be used to supplement the summer flow of the Consumnes.

On June 9, 1911, the Consumnes Irrigation Company filed a notice of appropriation for 5,000 inches of the water of the Consumnes River- As shown by the table of discharge this project will have a supply only in the early irrigation season.

MOKELUMNE RIVER.

The Geological Survey has maintained a gaging station on the Mokelumne River at Electra for the year 1904 and near Clements for the period 1905-1910. The mean monthly discharge is shown on Table XLIV. The average mean for the seven year period for August was246 second feet and for September 150 second feet. The average mean for the low water years 1905,1908 and 1910 for July was 196 second feet, for August 99 second feet, and for September 116 second feet.

The entire summer flow of the stream has been appropriated by the Stockton-Mokelumne Canal Company which owns the only system diverting water from the Mokelumne River on the floor of the valley. The system covers 32,000 acres but the area actually irrigated has never exceeded one-tenth of that amount. There is now a movement on foot to form an irrigation district and purchase the system. If this is done the result will undoubtedly be a much increased irrigated territory.

Formerly the water was distributed on a rental basis but the present company controlling the system has suggested the sale of water rights on the basis of 1 second foot to 160 acres. On this basis the 32,000 acres would require 200 second feet so that the demands of the system will be in excess of the August supply except in wet years and will always be in excess of the September supply.

There are a number of mountain meadows and mountain lakes now utilized as reservoirs on the

headwaters of the Mokelumne by the Pacific Gas and Electric Company. A number of small reservoir sites are known in addition to those already developed but the Pacific Gas and Electric Company does not now intend to use them and they are so small that it is not likely that they will be utilized for irrigation purposes alone.

There are in excess of 300,000 acres of land which are commanded by the Mokelumne. This is a larger area than can be watered from this river. All of the water at low stages will ultimately be in irrigation canals.

CALAVERAS RIVER.

The Geological Survey has maintained a gaging station on Calaveras River at Jenny Lind for the period 1907-1910. The mean monthly discharge is shown in Table XLV. As shown by the table, no figures are given for the summer months and as explained by the foot-note, "the flow is small during the period of missing records, the river going entirely dry in mid-summer."

Early in 1910 a corporation was organized under the auspices of the Stockton Chamber of Commerce "to promote the impounding of the waters of the Calaveras basin for the purpose of preventing floods and incidentally to supply usable storage of flood water for irrigation, power, etc." The company has surveyed a reservoir site which has a capacity of 206,500 acre feet. As shown in the quotation above, if this reservoir be constructed it will be primarily to relieve the flood situation and incidentally for power and irrigation. Those interested in the project hope to irrigate from 35,000 to 40,000 acres adjacent

to the river. No steps towards actual construction have been taken.

STANISLAUS RIVER.

The Geological Survey has maintained a gaging station on Stanislaus River at Oakdale from June 1895 to December 1900 and at Knight's Ferry from 1904 to 1910. The mean monthly discharge is shown in Table XLVI. The average mean for the six year period 1895-1900 for July was 778 second feet, for August 199 second feet and September 219 second feet. The average mean for the seven year period 1904-1910 for August was 457 second feet and for September 210 second feet.

The canal system of the Stanislaus Power and Irrigation Company which is the only one diverting water from the Stanislaus in the San Joaquin Valley, was recently purchased by two irrigation districts formed under the State Irrigation District Act- the South San Joaquin District embracing 71,050 acres and the Oakdale District embracing 65,940 acres. On a basis of 1 second foot to 160 acres the two districts (136,990 acres) will require 856 second feet. This amount exceeds the mean July flow for seven of the thirteen years, tabulated,and far exceeds the mean August flow in every year excepting the very wet years 1906 and 1907. It is evident, therefore, that without storage the districts will at times be short of water.

The South San Joaquin District plans to use a foothill reservoir site of about 75,000 acre feet capacity.

The following reservoir sites have been reported by the Geological Survey and the City of San Francisco on the tributaries of the Stanislaus:

Donnells Flat	46,000	acre feet capacity.
Kennedy Meadow	4,600	" " "
Kennedy Lake	2,000	" " "
Bear Valley	6,900	" " "
	59,500	" " "

No plans for their development in the near future are known.

The Sierra and San Francisco Power Company completed its Relief reservoir of 20,300 acre feet capacity in 1909 and operated it in 1910. Its increment to the summer flow is therefore included in the monthly mean for 1910. The Company expects to utilize additional storage but has made no definite plans.

The development by power companies of all known mountain reservoir sites on the Stanislaus would not relieve the Districts of the necessity of storage in foothill reservoirs, so that there will be no surplus summer flow in the Stanislaus.

TUOLUMNE RIVER.

The Tuolumne is not considered herein as it is to be made the subject of a special report.

MERCED RIVER.

The Geological Survey has maintained a gaging station upon the Merced River above Merced Falls for the period 1902-1910. The mean monthly discharge is shown in Table XLVII. The average mean for the nine year period for July was 1,671 second feet, for August 390 second feet and for September 183 second feet. Excluding the wet years 1906, 1907 and 1909, the average for July was only 628 second feet and the average mean for August only 239 second feet.

There are 234,550 acres under existing ditches from Merced River, of which only 32,554 were irrigated in 1909. The only large system is that of the Crocker-Huffman Land and Water Company which covers 220,000 acres. On a basis of 1 second foot to 160 acres, this area would require 1,375 second feet, which for the period, is in excess of the mean July flow except in wet years and every year in excess of the August and September flow.

The only reservoir sites reported are Little Yosemite, 45,195 acre feet, and Lake Tenaiya, 23,082 acre feet. As these sites are in the Yosemite National Park, it may be difficult to secure the right to utilize them. From the above showing of shortage of stream flow it is apparent that they are much needed.

FRESNO RIVER AND CHOWCHILLA CREEK.

These streams are torrential in character as their watersheds do not extent into the high snow-capped mountains. No stations have been maintained on them by

the Geological Survey. The California State Engineering Department prepared tables of flow for the period 1879-1883, copies of which are presented in Tables XLVIII and XLIX. There is practically no flow after early June.

The principal diversion from the Fresno River is that of the Madera Canal and Irrigation Company. Its system covers 40,000 acres and irrigated 8,700 in 1909.

A few years ago the Company attempted to divert part of the storm flow for storage in a small reservoir but was restrained from so doing by the decision of Miller vs. Madera Canal and Irrigation Company, 155 Cal. 59, which held that as flood waters are but part of the natural flow, Miller as a riparian owner had the right to them as against a mere appropriator. The Company had planned to use a number of such sites and by storage increase the efficiency of its system, but the above decision puts an end to development.

The Buchanan reservoir site on Chowchilla Creek has a capacity of 42,000 acre feet and the owners of existing canals on the creek are desirous of utilizing it. As its use would be open to the same objection as the Madera Company's site, no plans for its construction in the near future have been made.

SAN JOAQUIN RIVER.

The Geological Survey maintained a gaging station on the San Joaquin at Herndon for the period 1895-1901 and near Friant for the period 1908-1910. The mean

monthly discharge is shown in Table L. The average mean for the ten years considered for July was 2,751 second feet, for August 1,014 second feet, and for September 511 second feet. The average mean for the seven year period 1895-1901 for July was 2,704 second feet, for August 1005 second feet and for September 423 second feet.

There are 506,000 acres under existing ditches from the San Joaquin River and 175,740 acres were irrigated in 1909. On the basis of 1 second foot to 160 acres the 506,000 acres would require 3,162 second feet and 175,740 acres 1,099 second feet. The former amount exceeds the average mean flow for July and the latter exceeds the average mean flow for August. Many thousands of acres included in the area irrigated are pasture and wild hay lands and are watered only in the early season when water is abundant.

The largest system in the two valleys is the San Joaquin and Kings River Canal which covers 340,000 acres on the west side of the river. It has been involved in much litigation over water rights and in the recent case, California Supreme Court on March 20,1911, it was enjoined from diverting water in excess of 760 second feet. A rehearing has been granted, however, so the case is still undecided. The San Joaquin and Kings River Canal Company contends that it should be allowed at least 1,000 second feet. Stevenson is the owner of the East Side Canal which covers about 50,000 acres on the east side of the river- its head being about 30 miles below the head of the San Joaquin and Kings River Canal.

The main canal and part of the lateral system for the Patterson project lying immediately north of the San Joaquin and Kings River Canal Company's project have been completed and the laterals will be extended to cover 19,000 acres. The project is divided into five zones and water is pumped from one zone to the next higher. The pumping plant at the river has a capacity of 110 second feet. The Company is now meeting with marked success in securing settlers and most of the land is sold for $250. per acre.

On August 11, 1911, notice of the appropriation of water was filed for 300 second feet to be pumped from the San Joaquin River to the west side of the valley in San Joaquin County. On August 28th, 1911, the statement was published that plans had been completed for the pumping of the waters of the San Joaquin to 35,000 acres on the west side in Contra Costa County. It is too early to know what actual construction will be done on these projects, but they emphasize the interest that is being taken in pumping projects on the west side. The success of the Patterson project is paving the way for the subdivision of the large grain ranches on the west side and their irrigation by pumping from the San Joaquin. There are upwards of 100,000 acres north of the Patterson project which might be irrigated by pumping from the river.

As shown above, there is a shortage of water for the projects farthest up on the river. The San Joaquin Light and Power Corporation is now building two

reservoirs on the tributaries. One, the Crane Valley, with a capacity of 50,000 acre feet, has just been completed, and the other, the Big Creek, of 106,000 acre feet capacity, will be completed in two years. The Company intends to discharge from the Crane Valley reservoir 100 second feet during July, August and September and from the Big Creek reservoir 230 second feet during the same period- a total of 330 second feet. If the San Joaquin and Kings River Canal Company be restricted to 760 second feet and could arrange for the exclusive use of this expected discharge of stored water, the total of 1,090 second feet (allowing nothing for losses between the reservoirs and the Canal head, which losses would be material) would irrigate but 174,400 acres of the 340,000 under the system on the basis of 1 second foot to 160 acres.

The manager of the Power Company has stated that the other storage sites in the upper San Joaquin basin which have come to his attention are situated in the highest part of the watershed and the prospects for their development are very remote.

It is claimed by residents of the valley that a very good site is situated on the main river just above Pollasky where the river breaks into the valley. The site has never been surveyed and its value is therefore conjectural.

As the storage opportunities on the San Joaquin and its tributaries are so few, it is certain that the upper ditches will take the entire summer flow, so that

pumping projects on the lower west side must depend entirely on return waters from irrigation in higher parts of the valley. In the matter of the quantity of return flow each valley is a law unto itself and it is useless to theorize on the probable amount in the absence of actual measurements.

The engineers of the Patterson project began measuring the discharge of the river near the pumping station late in 1910. On November 10, the flow was 360 second feet and on December 7th, 384 second feet. As these measurements were taken long after the close of the irrigation season most of the waters from upper San Joaquin and Merced should have passed the gaging station. The mean flow of the Merced in November and December 1910 was 190 and 290 second feet respectively, and of the San Joaquin near Friant, 403 and 510 respectively. The Patterson measurements were taken about ten miles above the mouth of the Tuolumne and opposite the lower part of the Turlock Irrigation District, so that some of the return water from the district was included in the measurement. Excluding the Turlock district, seventy per cent of the entire area irrigated in the valley was well above the gaging point. It seems probable, therefore, that the amount of return water to the San Joaquin is very small.

Assuming that the full amount shown in the Patterson measurements was return water, the probable supply for projects below is still very questionable. The Patterson project will divert at least 110 second feet when fully developed, and each future ten thousand acre project below it, at least 63 second feet. The amount of return water for the remaining part

of the valley would have to be very much greater in order to meet the demands of many such projects. It seems certain that in the drier years there would not be sufficient for the irrigation of 100,000 acres on the west side below Patterson.

DUTY OF WATER.

In the above discussion the duty of water has been assumed to be 1 second foot to 160 acres as that is the duty in "water right" agreements of the Butte County Canal Company, the Madera Canal and Irrigation Company, the Crocker-Huffman Land and Water Company, and the Stockton Mokelumne Canal Company. It has been fixed by the Los Molinos Land Company at the equivalent of 1 second foot to 230 acres, and by the Sacramento Valley Irrigation Company, assuming the irrigation season to extend over six months, at 1 second foot to 240 acres. As the last two systems have not been completed, there has been no attempt to limit the present users to the stipulated quantity. Under the other systems no attempt has been made to measure the water and users have secured what they could while the supply lasted.

The office of Irrigation Investigations has made a number of measurements of water used in the two valleys and the results are given below.

In 1906 the average depth of water applied in single irrigations of alfalfa on twelve tracts under the Moore Ditch in Yolo County was 0.83 feet, or 0.69 excluding one tract of a very sandy soil. (O. E. S. Bulletin 207, page 42) The average depth of irrigation for the season

of 1906 for six fields of alfalfa near Orland, Glenn County, was 4.50 feet, the depth for single fields varying from 3.64 feet to 15.08 feet. (O. E. S. Bulletin 207, page 97).

From measurements made in 1909 and 1910 in Modesto and Turlock districts seasonal depths for alfalfa varying from 8.60 feet to 1.80 feet were determined, with an average for seventeen farms of 3.83 feet. (O. E. S. Circular 108, pages 13 and 14). The duty under the San Joaquin and Kings River Canal and Irrigation Company for the period July 1, 1906 to June 30, 1908, as shown by the Company's records of water delivery was as follows: (O. E. S. Circular 108, page 117)

"July 1, 1906 to June 30,1907; Alfalfa 1.89; grain 0.74; corn, 213; orchard, 2.64; vineyard, 2.32; potatoes, 1.00; garden, 2.44; grass, 1.23;

July 1, 1907 to June 30,1908; Alfalfa 2.23; grain, 0.84; corn, 1.65; sorghun, 1.02; orchard, 2.45; garden, 2.91; grass, 0.60;

The following quotation shows the results of experiments at the State Farm at Davis (O. E. S. Circular 1908, page 14)

"Of the 30 plats, 8 received no water in 1910. Six cuttings gave an average yield of 4.08 tons per acre.

Two plats received a depth of 24 inches and yielded 6.43 tons per acre as the total of six cuttings. This shows an increase of 1.64 tons over the yield of 4.79 tons on the plats receiving but 12 inches.

Twelve plats were given a total seasonal depth of 30 inches and yielded an average of 8.09 tons per acre.

On three plats the depth of water applied was 36 inches and an average yield of 7.60 tons was produced which is 0.49 tons less than the yield from the plats receiving 30 inches of water.

The last three plats, which received 48 inches, yielded 8.45 tons per acre.

While the results as stated show a substantial increase in yield with the increased water applied up to 30 inches, above that amount the increase was not in proportion to the water applied. This is not, however, conclusive that 30 inches is all of the water that should be applied to alfalfa, but that such an amount will produce very satisfactory results. Further experiments will be made as to the effects of larger quantities."

A duty of 1 second foot to 160 acres is equivalent to a depth of 4½ inches per month and 2.25 feet for a season of six months. In the measurements reported above the water was measured at or near the irrigated field, so that all losses in transmission were eliminated. This transmission loss often amounts to fifty per cent on the larger systems. The average loss per mile for a number of valley ditches is shown in the following table taken from O. E. S. Circular 108, page 29.

Year	Canals	Source of Location	Length of Section Measured	Flow in Canal	Average loss per mile
			Miles	Sec. ft.	Per Cent
1904	Modesto#	Tuolumne Riv.	22.0	78-242	.70
1904	"	"	33.0	260	1.70
1904	Turlock	"	22.0	115-491	.80
1906	Moore	Cache Creek		86-116	4.80
1907	"	"	4.0	63-127	4.50
1907	Capay-Winters	"		40- 80	6.40
1907	Central	Sacramento Riv.	11.0		3.40
1908	San Joaquin & Kings River	San Joaquin Riv.	5.0	190-239	.45
1909	Modesto	Tuolumne Riv.	22.0	532	.30
1909	Turlock	"	22.0	879	.20
1910	Modesto	"	18.0	793	.17

Seasonal.

It is clear that a duty of 1 second foot to 160 acres at the headgate means a much higher duty at the irrigated field and it is not to be expected that the average system will maintain so high a duty in the near future.

RIVER DISCHARGE
SACRAMENTO AND SAN JOAQUIN VALLEYS.
Compiled from the records of the United States Geological Survey
(For the discharge of Tuolumne River see Table I and II)

TABLE XXXIV.

Sacramento River at Iron Canyon near Red Bluff.

Drainage Area = 9,300 square miles. Second Feet

Month:	1895-96#:	1896-97#:	1897-98#:	1898-99#:	1899-1900#:	1900-01#:	1901-02#
Oct :	:	6,183 :	4,055 :	4,631 :	5,063 :	6,381 :	4,914
Nov :	:	11,965 :	5,500 :	4,785 :	14,532 :	8,805 :	7,745
Dec :	:	22,318 :	7,732 :	4,991 :	14,519 :	15,533 :	12,149
Jan :	43,152 :	14,280 :	6,130 :	13,498 :	30,681 :	20,983 :	5,376
Feb :	15,468 :	38,108 :	12,479 :	8,648 :	11.687 :	34,138 :	6[illegible],153
Mar :	24,093 :	21,790 :	9,745 :	20,915 :	23,288 :	20,628 :	8[illegible],371
Apr :	23,793 :	22,807 :	6,872 :	10,837 :	12,082 :	10,870 :	31,992
May :	30,941 :	13,737 :	6,332 :	6,908 :	9,572 :	9,304 :	17,803
June :	14,217 :	7,680 :	6,674 :	6,199 :	5,477 :	5,596 :	8,998
July :	7,591 :	5,699 :	4,700 :	4,531 :	4,212 :	4,385 :	6,192
Aug :	6,394 :	4,776 :	4,276 :	3,986 :	3,805 :	3,850 :	5,674
Sept :	6,304 :	4,600 :	4,230 :	3,980 :	3,931 :	3,828 :	5,007
The Year-		14,320 :	6,678 :	7,653 :	11,573 :	12,023 :	16,114

#1895-1903 At Jellys Ferry. 9,134 square miles. (They vary in different reports)

TABLE XXXIV (Continued)

Drainage area= 3,300 sq.miles. Second Feet

Month:	1902-03:	1903-04:	1904-05	:1905-06	:1906-07:	1907-08:	1908-09
Oct	5,931	5,347	10,990	5,155	5,870:	5,870	5,230
Nov	19,834	21,955	8,932	5,616	6,570:	6,200	6,060
Dec	17,508	13,101	13,875	6,100	15,400:	11,600	6,370
Jan	35,561	11,489	31,830	14,700	21,500:	21,000	72,900
Feb	17,186	46,346	26,800	23,200	45,400:	23,200	63,900
Mar	31,555	73,381	30,930	42,500	55,700:	15,000	25,500
Apr	18,791	38,906	18,680	26,300	32,200:	11,900	19,500
May	10,948	25,080	12,750	19,400	15,500:	10,700	13,800
June	6,970	12,362	8,623	18,100	12,200:	7,560	9,890
July	5,589	8,656	6,075	8,530	7,550:	5,570	6,840
Aug	4,965	6,348	5,251	6,330	6,260:	4,830	5,710
Sept	4,813	8,530	5,062	6,020	5,830:	4,710	5,560
The Year	14,137	22,450	14,899	15,163	18,165:	10,678	20,105

TABLE XXXIV (Continued)

Month:	1909-10:	1910
Oct	6,250	5,170
Nov	12,300	6,510
Dec	16,100	10,300
Jan	16,300	
Feb	21,800	
Mar	28,900	
Apr	16,000	
May	9,310	
June	6,280	
July	5,320	
Aug	4,860	
Sept	4,940	
	12,355	

TABLE XXXV.

Mean monthly discharge of Stony Creek, near Fruto, Cal.

Drainage area = 760 square miles. In second feet.

Month	1900-01#	1901-02	1902-03	1903-04	1904-05
October		130	93	16	167
November		161	1,584	613	71
December		425	1,138	462	453
January#		114	1,483	834	2,480
February	3,707	4,801	1,067	3,800	1,471
March	893	2,588	1,663	4,364	2,050
April	361	1,523	892	1,604	870
May	349	578	276	715	675
June	66	132	16	165	306
July	7	3	7	34	36.5
August	4	3	10	14	18.4
September	35	9	8	19	13.7
The Year		822	682	1,003	704

TABLE XXXV (Continued)

Month	1905-06	1906-07	1907-08	1908-09+	1909-10 +	1910 +
October	16.3	23.0	30	34.0	47.4	13.2
November	37.1	61.4	44	83.3	370	48.5
December	88.1	582	597	198	651	34.5
January	1,230	2,080	1,140	6,560	437	
February	1,540	3,310	1,680	5,460	933	
March	3,500	4,430	903	1,600	1,780	
April	1,220	1,640	525	986	731	
May	610	450	364	486	841	
June	495	236	186	145	75.0	
July	127	47.1	47.6	41.0	14.2	
August	38.6	15	14.8	15.9	8.94	
September	17.3	10	8.83	13.8	5.60	
The Year	745	1,070	469.	1,260.	483	

Station established January 30,1901. 11 months records 1901.

+ Drainage area given as 601 square miles.

TABLE XXXVI.

Mean monthly discharge of Cache Creek at Lower Lake, Cal.

Drainage area = 500 square miles. In second feet

Month:	1900-01:	1901-02:	1902-03:	1903-04:	1904-05 :	1905-06 :
Oct :	:	31 :	127 :	22 :	168 :	56 :
Nov :	:	36 :	263 :	54 :	143 :	30.1 :
Dec :	:	62 :	307 :	168 :	165 :	30.7 :
Jan :	535 :	53 :	379 :	216 :	448 :	316 :
Feb :	909 :	381 :	712 :	541 :	884 :	876 :
Mar :	1,079 :	1,766 :	724 :	3,588 :	933 :	1,220 :
Apr :	654 :	1,427 :	740 :	3,801 :	991 :	1,510 :
May :	481 :	865 :	533 :	1,460 :	702 :	894 :
June :	337 :	556 :	336 :	762 :	476 :	639 :
July :	199 :	380 :	208 :	483 :	294 :	423 :
Aug :	114 :	243 :	111 :	302 :	173 :	256 :
Sept :	55 :	183 :	50 :	188 :	92.5:	150 :
The Year		496 :	374 :	799 :	456 :	517 :

TABLE XXXVI (Continued)

Month :	1906-07:	1907-08 :	1908-09 :	1909-10 :	1910
Oct :	103 :	132 :	9.53 :	103 :	6.71
Nov :	79.4:	109 :	7.68 :	98.1:	4.77
Dec :	133 :	142 :	15.2 :	177 :	5.16
Jan :	404 :	300 :	1,130 :	263 :	
Feb :	850 :	634 :	3,940 :	482 :	
Mar :	1,790 :	726 :	3,010 :	555 :	
Apr :	2,450 :	566 :	1,860 :	576 :	
May :	1,360 :	383 :	949 :	404 :	
June :	766 :	240 :	598 :	259 :	
July :	467 :	145 :	397 :	146 :	
Aug :	298 :	83.0:	246 :	77.6:	
Sept :	188 :	32.0:	148 :	21.3:	
The Year	741 :	291 :	1,025 :	283 :	

TABLE XXXVII

Mean Monthly Discharge of Cache Creek at Yolo, Cal.

Drainage = 1,230 square miles. In second feet.

Month	1902-03	1903-04	1904-05	1905-06	1906-07
Oct		0	254	.32	13.6
Nov		412	120	0	0
Dec		325	469	0	435
Jan	1,036	183	2,313	2,000	1,750
Feb	1,506	3,166	2,142	1,660	2,360
Mar	1,315	5,591	1,969	3,040	5,380
Apr	1,052	3,188	1,576	2,360	3,580
May	545	1,656	1,058	1,270	1,430
June	276	681	542	784	747
July	63	316	214	333	481
Aug	2	117	86.5	166	189
Sept	0	82	7.1	69	36
The Year		1,310	896	974	1,362

TABLE XXXVII (Continued)

Month	1907-08	1908-09	1909-10	1910
Oct	40	0	18	0
Nov	67	0	32	0
Dec	188	0	391	0
Jan	792	5,390	7[illegible]	
Feb	1,350	8,450	890	
Mar	1,270	4,040	1,010	
Apr	662	2,070	727	
May	310	908	317	
June	66	496	31	
July	5	240	0	
Aug	0	86	0	
Sept	0	7	0	
The Year	466	1,807	348	

TABLE XXXVIII.

Mean monthly discharge of Putah Creek, at Winters, Cal.

Drainage area = 805 square miles. In second feet

Month:	1903-04#	1904-05#	1905-06	1906-07	1907-08	1908-09	1909-10
Oct		80	15	13	17	4	16
Nov		42	10	34	24	7	59
Dec		831	22	836	197	138	745
Jan	30+	1,344	3,100	2,320	808	7,370	1,120
Feb	2,515	619	1,330	1,880	1,390	5,500	844
Mar	2,168	630	3,060	5,150	662	1,180	762
Apr	279	288	1,130	919	120	457	300
May	89	120	411	230	64	137	87
June	31	85	208	110	27	73	26
July	16	13	72	39	7	23	8
Aug	11	8	21	16	5	11	5
Sept	13	10	14	15	4	10	3
The Year		338	738	[illegible]	278	1,241	315

TABLE XXXVIII (Continued)

Month :	1910
Oct :	3
Nov :	8
Dec :	34
The Year	

Near Guenoc, Cal. Drainage area = 91 square miles.

\+ Estimated.

TABLE XXXIX.

Mean monthly discharge of Feather River at Oroville, Cal.

Drainage area = 3,350 square miles. In second feet

Month	1901-02:	1902-03:	1903-04:	1904-05:	1905-06:	1906-07:
Oct		1,503	1,464	4,137	1,286	1,920
Nov		3,481	19,934	2,566	1,381	2,410
Dec		6,287	4,213	5,874	1,385	7,070
Jan	1,998	7,517	3,396	9,860	14,500	7,130
Feb	13,545	5,431	27,766	9,612	11,100	21,500
Mar	11,148	11,973	39,589	13,560	21,600	36,900
Apr	12,485	19,165	24,468	9,403	19,200	29,500
May	13,110	10,019	17,751	7,254	17,500	23,400
June	5,609	4,329	7,459	4,098	13,800	15,200
July	3,008	2,102	2,910	1,790	5,240	6,000
Aug	1,535	1,506	1,964	1,354	2,490	2,650
Sept	1,323	1,233	2,252	1,273	1,970	1,900
The Year		6,212	12,750	5,888	9,283	12,963

TABLE XXXIX(Continued)

Month:	1907-08:	1908-09#:	1909-10# :	1910# :
Oct	1,850:	1,650	1,960	1,200
Nov	1,780:	1,750	5,750	1,860
Dec	6,060:	1,910	8,140	3,400
Jan	6,510:	39,900	6,750	
Feb	6,380:	18,400	7,970	
Mar	7,250:	13,400	17,900	
Apr	9,210:	15,900	13,600	
May	8,170:	14,000	6,850	
June	5,310:	9,060	2,620	
July	2,320:	3,270	1,600	
Aug	1,510:	1,800	1,350	
Sept	1,250:	1,820	1,170	
The Year	4,808:	10,238	6,322	

Drainage area is given as 3,640 square miles.

TABLE XL/

Mean monthly discharge of Yuba River near Smartsville,Cal.

Drainage area - 1,230 square miles. In second feet

Month	1902-03	1903-04	1904-05	1905-06	1906-07
October		550	1,855	453	403
November		4,893	1,180	474	757
December		8,008	2,290	566	4,130
January		1,924	4,903	7,560	4,990
February		14,913	5,008	4,870	14,100
March		15,399	7,107	12,000	17,300
April		10,638	6,731	9,770	13,100
May		10,561	6,071	10,800	8,750
June	2,911	4,650	3,101	10,000	6,750
July	899	1,156	782	3,350	3,060
August	516	580	471	744	736
September	479	637	439	580	505
The Year		5,659	3,338	5,017	6,215

TABLE XL (Continued)

Month	1907-08	1908-09	1909-10	1910
October	517	521	543	388
November	472	478	4,810	653
December	1,590	764	6,550	1,400
January	3,380	23,000	4,530	
February	2,230	9,740	4,390	
March	3,590	5,330	8,170	
April	4,800	7,340	7,300	
May	5,200	8,450	4,690	
June	3,180	6,520	1,280	
July	705	1,360	585	
August	350	805	338	
September	329	431	383	
The Year-	2,195	5,378	3,674	

TABLE XLI.

Mean monthly discharge of Bear River at Van Trent, Cal.

Drainage area = 65 square miles. In second feet

Month	1904-05	1905-06	1906-07	1907-08	1908-09	1909-10	1910
Oct		32	36	44	51	53	35
Nov		23	90	51	54	269	46
Dec		39	1,770	383	145	979	105
Jan	1,058	3,130	1,300	731	4,180	914	
Feb	975	1,500	2,810	535	2,180	709	
Mar	1,300	3,970	3,350	553	748	788	
Apr	576	1,390	1,300	516	409	302	
May	615	870	494	208	166	117	
June	193	544	282	142	88	48	
July	37	113	84	40	46	24	
Aug	38	86	39	30	37	21	
Sept	37	26	38	31	40	22	
The Year		980	958	270	679	354	

TABLE XLII.

Mean monthly discharge of American River at Fair Oaks, Cal.

Drainage area = 1,910 square miles. In second feet

Month	1904-05	1905-06	1906-07	1907-08	1908-09	1909-10	1910
Oct		138	338	693	384	511	342
Nov	896	191	587	831	441	4,590	538
Dec	1,404	242	3,900	1,790	605	7,670	1,600
Jan	3,549	7,010	4,150	3,600	24,300	8,520	
Feb	4,630	5,830	14,800	1,960	15,500	5,240	
Mar	8,934	13,900	24,700	3,290	6,460	10,500	
Apr	7,736	12,100	15,600	4,480	7,990	10,500	
May	6,717	15,000	12,800	4,590	9,510	7,950	
June	3,831	15,900	11,100	2,600	7,650	2,360	
July	719	6,180	5,510	870	3,310	516	
Aug	255	1,010	1,500	200	607	213	
Sept	126	433	813	123	287	301	
The Year		6,494	7,938	2,003	6,337	4,389	

TABLE XLIII

Mean monthly discharge of Co sumnes River at Michigan Bar, Cal.

Drainage area = 534 square miles. In second feet

Month	1907-08	1908-09	1909-10	1910
October	73	13	85	19
November	87	27	343	47
December	195	48	1,130	113
January	471	4,300	1,321	
February	306	2,750	1,050	
March	552	1,360	2,210	
April	346	1,230	1,150	
May	359	642	414	
June	106	281	96	
July	15	42	20	
August	0	8	4	
September	1	9	10	
The Year	208	951	639	

TABLE XLIV

Mean monthly discharge of Mokelumne River near Clements, Cal.

Drainage area = 642 square miles. In second feet

Month	1903-04#	1904-05	1905-06	1906-07	1907-08	1908-09	1909-10	1910
Oct		827	114	190	276	142	131	107
Nov		189	794	348	334	134	951	170
Dec		315	970	876	328	161	1,500	356
Jan	157	428	996	1,140	537	2,910	1,340	
Feb	2,431	853	806	2,780	393	2,260	947	
Mar	4,170	1,410	2,520	4,880	817	1,870	2,390	
Apr	3,780	1,859	2,540	4,430	1,730	2,810	3,240	
May	5,411	2,547	4,700	4,280	1,900	3,710	3,180	
June	3,307	1,665	6,030	4,720	1,280	4,310	1,000	
July	722	188	3,540	3,330	329	834	178	
Aug	111	138	356	703	104	115	84	
Sept	165	139	203	257	135	77	74	
The Year		887	1,987	2,314	662	1,593	1,249	

TABLE XLV

Mean monthly discharge of Calaveras River at Jenny Lind.

Drainage area = 395 square miles. In second feet.

Month:	1906-07:	1907-08:	1908-09:	1909-10 :	1910
Oct :				13 :	
Nov :			28 :	200 :	44
Dec :		102 :	89 :	949 :	58
Jan :	1,570 :	343 :	3,070 :	795 :	
Feb :	1,920 :	285 :	3,450 :	269 :	
Mar :	5,830 :	214 :	811 :	642 :	
Apr :	718 :	102 :	375 :	305 :	
May :	255 :	81 :	110 :	91 :	
June :	157 :	37 :	55 :	33 :	
July :			14 :	9 :	
Aug :			2 :		
Sept :			2 :		
Year					

TABLE XLVI

Mean monthly discharge of Stanislaus River at (Knights Ferry,Cal.frm.
Drainage area (Knight's Ferry=935 sq.miles. 1904
" " (Oakdale =1,051 sq.miles. (Oakdale,Cal.from 1895-190

In second feet

Month:	1894-95:	1895-96:	1896-97:	1897-98:	1898-99:	1899-1900:	1900 :
Oct :		176 :	239 :	176 :	77 :	309 :	448 :
Nov :		179 :	705 :	255 :	71 :	1,092 :	1,220 :
Dec :		198 :	681 :	411 :	139 :	1,461 :	871 :
Jan :		1,806 :	609 :	207 :	457 :	1,944 :	
Feb :		782 :	3,332 :	389 :	355 :	700 :	
Mar :		2,464 :	1,915 :	572 :	2,425 :	1,829 :	
Apr :		3,274 :	5,084 :	1,813 :	3,525 :	1,761 :	
May :		4,717 :	7,324 :	1,378 :	2,559 :	3,343 :	
June :	5,686 :	6,541 :	2,077 :	647 :	2,683 :	1,863 :	
July :	1,778 :	1,293 :	582 :	167 :	502 :	349 :	
Aug :	330 :	385 :	198 :	66 :	150 :	64 :	
Sept :	638 :	332 :	152 :	61 :	85 :	46 :	
Year		1,012 :	1,900 :	518 :	1,083	1,230 :	

TABLE XIV

[illegible]

TABLE XVIII

[illegible]

TABLE XLVI (Continued)

Month	1903-04	1904-05	1905-06	1906-07	1907-08	1908-09	1909-10	1910
Oct		1,174	97	193	274	136	179	162
Nov		412	91	181	206	121	1,010	193
Dec		436	131	1,870	353	155	2,280	313
Jan	199	642	2,470	1,840	522	5,810	2,170	
Feb	4,712	1,386	2,070	3,580	518	4,050	1,560	
Mar	6,140	2,395	5,330	10,400	1,160	2,870	3,740	
Apr	5,389	2,774	5,330	8,110	2,390	4,890	5,150	
May	3,547	3,847	8,090	7,890	3,330	6,100	3,890	
June	4,508	2,382	9,240	7,500	1,360	5,600	1,480	
July	1,895	613	5,210	4,370	501	1,440	388	
Aug	372	150	910	1,070	208	344	146	
Sept	261	103	309	373	117	160	142	
Year		1,305	3,282	3,864	819	2,627	1,836	

TABLE XLVII.

Mean monthly discharge of Merced River above Merced Falls, Cal.

Drainage area = 1,090 square miles. In second feet

Month	1901-02	1902-03	1903-04	1904-05	1905-06	1906-07
October		90	275	1,511	59	132
November		246	381	471	66	135
December		303	389	361	97	735
January	336	1,118	139	345	1,840	2,040
February	749	1,103	1,240	1,105	1,060	3,100
March	1,387	1,950	2,235	1,774	4,660	7,480
April	2,457	2,877	3,708	2,050	3,500	5,480
May	3,795	4,380	5,797	3,316	6,530	8,370
June	3,143	3,944	3,232	2,980	3,410	3,330
July	481	696	909	804	1,260	3,480
August	191	369	330	158	948	792
September	88	279	325	82	254	319
Year	1,358	1,511	1,245	1,807	2,938	

TABLE XLVII (Continued)

In second feet.

Month	1907-08	1908-09	1909-10	1910
October	135	94	133	171
November	154	69	531	190
December	308	105	1,680	290
January	517	3,700	2,260	
February	496	3,330	874	
March	1,040	1,380	1,930	
April	1,870	2,890	4,010	
May	3,000	3,330	4,070	
June	1,270	5,950	1,380	
July	488	1,530	591	
August	303	336	132	
September	93	138	191	
The Year	714	2,055	1,472	

TABLE XLVIII #

Mean monthly discharge of Fresno Creek(Madera Co.) at base of foothills.

Drainage area = 272 square miles. In second feet

Month	1878-79	1879-80	1880-81	1881-82	1882-83	1883
October		0	0	0	27	0
November		0	0	0	54	0
December		109	218	27	27	0
January	27	5	544	54	82	
February	80	150	544	163	54	
March	118	16	272	1,088	272	
April	156	1,088	109	292	136	
May	79	54	54	54	109	
June	15	27	0	0	0	
July	0	0	0	0	0	
August	0	0	0	0	0	
September	0	0	0	0	0	
The Year		181	145	140	63	

Authority, California State Engineering Department.

November and December, 1878, and from November 1879 to October 1884 inclusive, estimated from runoff of neighboring streams.

TABLE XLIX.

Mean monthly discharge of Chowchille Creek at base of foothills.

Drainage area = 268 square miles. In second feet

Month	1878-79	1879-80	1880-81	1881-82	1882-83	1883
Oct		0	0	0	0	0
Nov		0	0	0	53	0
Dec		12	201	27	27	0
Jan	8	5	395	54	80	
Feb	56	167	375	164	53	
Mar	83	19	83	1,168	268	
Apr	48	1,266	11	268	134	
May	14	53	0	54	107	
June	0	27	0	0	0	
July	0	0	0	0	0	
Aug	0	0	0	0	0	
Sept	0	0	0	0	0	
The Year		129	80	145	60	

\# Authority, California State Engineering Department.

Run off for May, June, July, August, September, October, November, December, 1880, all months of 1881, all months of 1882 except February and March, all months of 1883 and 1884, estimated from previous measurements, or from runoff of neighboring streams.

TABLE L.

Mean monthly discharge of San Joaquin River near Friant, Cal.

Drainage area = 1640 square miles. In second feet

Month:	1894-95#	1895-96	1896-97	1897-98	1898-99	1899-1900
Oct		430	187	279	509	214
Nov		362	697	872	308	565
Dec		373	666	995	384	1,018
Jan	2,881	2,119	655	658	463	2,244
Feb	2,568	1,177	2,598	842	645	534
Mar	3,779	2,612	2,325	908	2,689	1,748
Apr	5,834	2,675	6,541	2,944	4,233	2,060
May	13,124	5,394	13,545	3,306	3,730	5,735
June	10,674	11,790	5,862	2,718	5,700	5,738
July	4,528	4,177	2,493	959	1,684	1,642
Aug	1,417	1,048	898	480	438	390
Sept	1,085	534	387	383	153	204
The Year		3,734	3,056	1,289	1,743	1,839

TABLE L(Continued)

Record discontinued at end of 1901, owing to constantly changing cross section. Restarted 1908 at Pollasky.

Month:	1900-01	1901-02	1907-08	1908-09	1909-10	1910
Oct	451	489		388	407	482
Nov	1,834	708	441	278	833	403
Dec	1,033	872	659	301	3,580	510
Jan	3,506		864	4,510	3,060	
Feb	4,983		1,010	3,290	1,560	
Mar	4,191		1,950	2,160	3,050	
Apr	4,680		3,350	5,910	6,310	
May	10,935		3,560	10,500	7,730	
June	11,998		3,960	13,900	3,990	
July	3,466		1,930	5,030	1,620	
Aug	2,373		1,190	1,270	644	
Sept	398		655	631	869	
Year	4,154			4,013	2,804	

Records for 1895 to 1901 taken at Herndon.